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HISTORIC STRUCTURE REPORT

STAPLE BEND TUNNEL
ALLEGHENY PORTAGE RAILROAD
NATIONAL HISTORIC SITE

PENNSYLVANIA

APRIL, 1991

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HISTORIC STRUCTURE REPORT

Staple Bend Tunnel

Allegheny Portage Railroad

National Historic Site

Pennsylvania

Prepared For

U.S. Department of the Interior/National Park Service

Prepared by:

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STAPLE BEND TUNNEL

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PREFACE

The Department of Interior has nearly completed negotiations with Bethlehem Steel Corporation to acquire property that contains various historic sites and artifacts. Among the historic sites is Staple Bend Tunnel, Allegheny Portage Railroad National Historic Site, located in Cambria County, Pennsylvania. Sellards & Grigg, Inc., and it's team were retained by the National Park Service to evaluate Staple Bend Tunnel. The specific focus of the evaluation is what would be needed to be able to open Staple Bend Tunnel to the general public as a resource with historical importance.

The Sellards & Grigg, Inc., team included:

Sellards & Grigg, Inc., Lakewood, Colorado	Civil/Structural
GEI Consultants, Inc., Winchester, Mass.	Geotechnical
Semple Brown Roberts, P.C., Denver, Colorado	Historical Architect
The EADS Group, Altoona, Pennsylvania	Surveyors

The National Park Service has had others prepare specific reports related to other aspects of Staple Bend Tunnel. These include a historical documentation of the tunnel also entitled "Historic Structure Report, July, 1990, prepared by A. Berle Clemenson, historian for the National Park Service, and a Management Report entitled, "Archeological Monitoring of Geotechnical Tests at Staple Bend Tunnel", February, 1991, prepared by the firm of Louis Berger & Associates, Inc., East Orange, New Jersey. These documents are included in this final Historic Structure Report as Attachments I and III, respectively.

Sellards & Grigg, Inc., wants to thank all those who have made a contribution to this report.

Thomas A. Young, P.E.
Project Manager for Sellards & Grigg, Inc.
Pennsylvania License No. PE-040262-R

EXECUTIVE SUMMARY

1. The tunnel is generally sound from a geological and structural viewpoint and can be accessible for visitation after corrective action is completed.

2. The concrete lining at the east portal provides structural support for the deformed east stone arch and should remain.

3. The east entry had a stone entry facade similar to (if not exactly like) the historic west facade.

4. Poor drainage and extensive vegetation are the main causes of deterioration to the tunnel and entries and must be addressed.

5. Historic stone retaining walls must be stabilized and enlarged and new retaining walls must be added to control erosion and structural stability.

6. A new retaining wall should be installed at and around the east entry arch to stabilize the historic arch and surrounding grade.

7. Solid infill panels or doors should be provided at each entry to weatherize the tunnel during periods of cold weather.

8. The stone lining is generally stable and needs only repointing.

9. The rock lining must be reviewed for loose, unstable material and be either removed, anchored in place or supported.

I. ADMINISTRATIVE DATA

A. Administrative Background

The Staple Bend Tunnel is a remote unit administered by Allegheny Portage National Historic Site in accordance with a cooperative agreement with Bethlehem Steel. Staple Bend Tunnel is presently owned by the Bethlehem Steel Corporation. National Park Service ownership is presently being negotiated.

The Draft General Management and Development Plan (January 1977) indicated several concerns about the site; extensive strip mining in the area may have damaged the environment; Japanese Bamboo, planted by Bethlehem Steel to reclaim damaged areas, is growing rampantly, and the Staple Bend unit faces the Cambria slag dump. Despite these concerns, the General Management Plan supported the idea that the Park Service should acquire the site. Primary interpretive emphasis would be the tunnel's significance in development of the nations railroads. Secondary emphasis would be its role as part of the Pennsylvania Canal. The General Management Plan recommended that a "Third part deed rights-of-way" for the trace of the railroad be acquired so historic scene restoration can be accomplished.

Access to and tours through the tunnel were not discussed in the GMP nor was the extent of restoration.

The Staple Bend Tunnel is not included in the List of Classified Structures at this time and has not been nominated yet for National Register Status. Nomination to the National Register of Historic Places is being coordinated with the State Historic Preservation Office and will be withheld until National Park Service ownership is secured.

B. Proposed Use

The actual use has not been determined at this time; however, the proposed use is to be as an interpretive tool complimentary to the Visitor Center presentation. Access for visitation will be limited and possibly restricted to guided tours.

The tunnel will be closed to access and viewing inside the tunnel during the off season. (Season to be determined by the Park Superintendent.)

The tunnel will be accessible, but protected by a restrictive gate, during the summer. The gate shall be open to allow viewing, but restrictive enough to prevent access for both humans and wildlife.

II. HISTORICAL BACKGROUND

The Allegheny Portage Railroad was constructed between 1831 and 1834 as part of a 394-mile transportation route between Philadelphia and Pittsburgh, Pennsylvania. In 1824, the Pennsylvania State Legislature enacted a mainline canal bill that authorized a Board of Canal Commissioners to design and construct canal systems across the state (Clemenson 1990:2). The 36-mile railroad section was established to traverse the Allegheny Mountains in western Pennsylvania, thereby connecting canal systems that terminated in Johnstown and Hollidaysburg.

Staple Bend Tunnel, located at a bend in the Little Conemaugh River immediately north of the head of Plane 1, was the first railroad tunnel to operate in the United States. Excavated through a 901-foot section of a promontory, the tunnel was completed following the removal of 14,900 cubic yards of bedrock. The total cost of tunnel construction amounted to $37,498.85.

The Principal Engineer for the Allegheny Portage Railroad, Sylvester Welch, located the proposed tunnel at the Staple Bend of the Little Conemaugh River and assigned it to Section 7:

"The tunnel is to be 900 feet long. Its transverse section to equal a prism 16 x 20 feet. The width at the bottom to be 20 feet. At the ends of the tunnel, some masonry will be required, but appearances indicate that the rock is sufficiently hard and strong within not to require arching." (Clemenson 1990:5)

The form of the roof or top of the vault will be determined by the character of the rock. The hill at the summit is 195.77 feet above the floor of the tunnel or grade of the road.

The contract to construction Section 7 was awarded to J and E Appleton on 25 May 1831. Tunnel excavation was completed in April 1833. The tunnel, with entry facades, was completed in June 1833.

The Portage Railroad opened in April 1834 and operated until Staple Bend Tunnel was abandoned in December 1852.

In 1837, a lead pipe was laid through the tunnel to carry water. (Clemenson 1990:8)

Staple Bend Tunnel was sold to the Pennsylvania Railroad on 25 June 1857. The rails were removed in 1858 and the tunnel was abandoned.

The American Pipe Line Company ran a water pipe through the tunnel around the turn of the century and sealed each entrance with a concrete wall. In 1951, the Bethlehem Steel Corporation laid a water pipe through the tunnel and modified the entry infill. At some point, a concrete lining was placed inside the stone arch to stabilize the East Portal. This may have occurred in 1951, but cannot be verified.

The Staple Bend Tunnel is presently closed off and used only as a water line easement for Bethlehem Steel Corporation.

III. STATEMENT OF SIGNIFICANCE

The Staple Bend Tunnel represents a transportation and engineering accomplishment during the infancy of America's railroad development. The Staple Bend Tunnel is nationally significant as the first railroad tunnel in the United States. The tunnel is significant also due to the engineering skill displayed in the construction and design; it was only the third tunnel to be built in the United States.

Architecturally, the ornate entry portals were well designed and constructed. The handsomely cut, carved and tooled masonry represents an excellent example of early industrial architecture and craftsmanship.

Limited archeological investigation has occurred at the tunnel entries and inside the tunnel. It appears that archeological significance may be limited due to the amount of disturbance caused by previous water line construction.

The historic period is from 1833-1852, the period of actual use by the Allegheny Portage Railroad.

IV. ARCHITECTURAL DATA SECTION

A. Existing Conditions

The Staple Bend Tunnel consists of three distinct elements: 1) the exposed rock tunnel; 2) the dressed stone arch lining; and 3) the tooled stone entry facade. (See figure 1.)

The exposed rock tunnel was laboriously constructed through the rock strata by a combination of hand drilling and explosives. The rock is exposed in the middle 600 foot portion of the tunnel. The physical characteristics and geotechnical information of the rock formation and exposed rock are discussed in Attachment II.

The stone arch lining, 150 feet long at each end of the tunnel, provided a structural transition from the tunnel entry points to stable rock.

The tooled stone entry facade served as a retaining wall for the earthen cover of the stone lining, as well as a stately architectural portal.

Together with dry laid stone retaining walls, which prevented erosion of the tunnel cover and retained existing slopes, the tunnel created a finely detailed entrance, set comfortably into the Allegheny hillside.

1. Stone Arch Lining

The stone lining is a transitional structural element which extends inside the tunnel 150 feet from the entry portals to the exposed stable rock. The stone arch is visible from the exterior of the entry and created the horseshoe shape of the tunnel lining. The stone arch is integral with the historic entry facade, but has structural capability of its own. The stone arch creates the tunnel support of the earth above until the natural rock formation provides structural support.

The arch is comprised of cut, beveled stones. The stones at the entry are of two basic lengths in order to begin masonry quoining. The individual stones are categorized in three basic shapes (See figure 2):

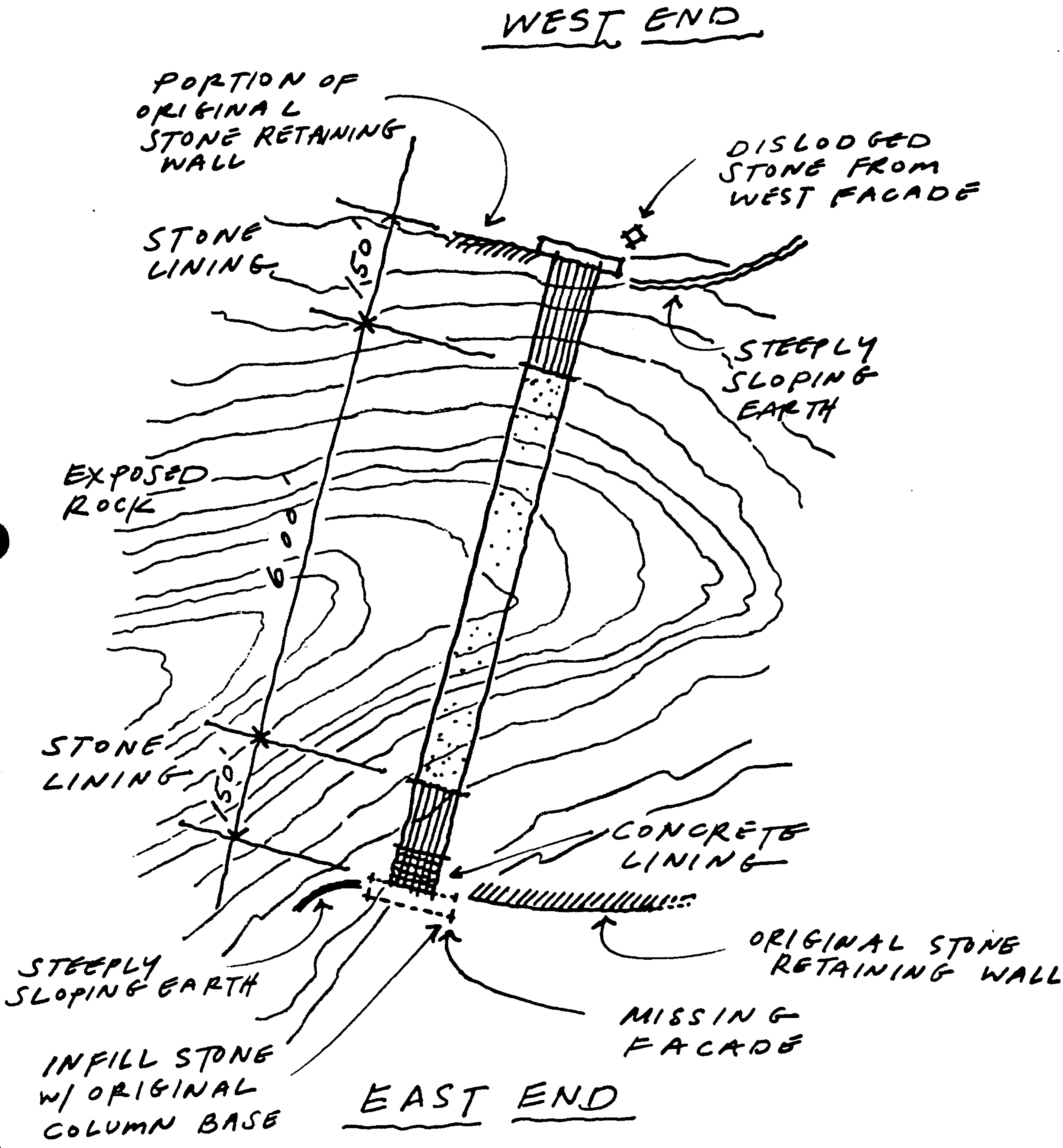
1. Trapezoidal shapes (voussiors)
2. Rectangular shapes (at base)
3. Flared shapes at bottom of arch

All stones are detailed with bevel edges and tooled on the bevels and front faces. (See figure 3.)

The arch stones appear to have been set with mortar, although the exterior joints are very narrow (1/8"±). Mortar does exist at many joints, both in the exterior face of the arch and at the joints inside the tunnel. Some joints have a hard, cementitious mortar; some joints are virtually all sand (probably due to the constant wet conditions of the tunnel); many joints have no mortar visible at all. (This is true for many stones overhead as well.)

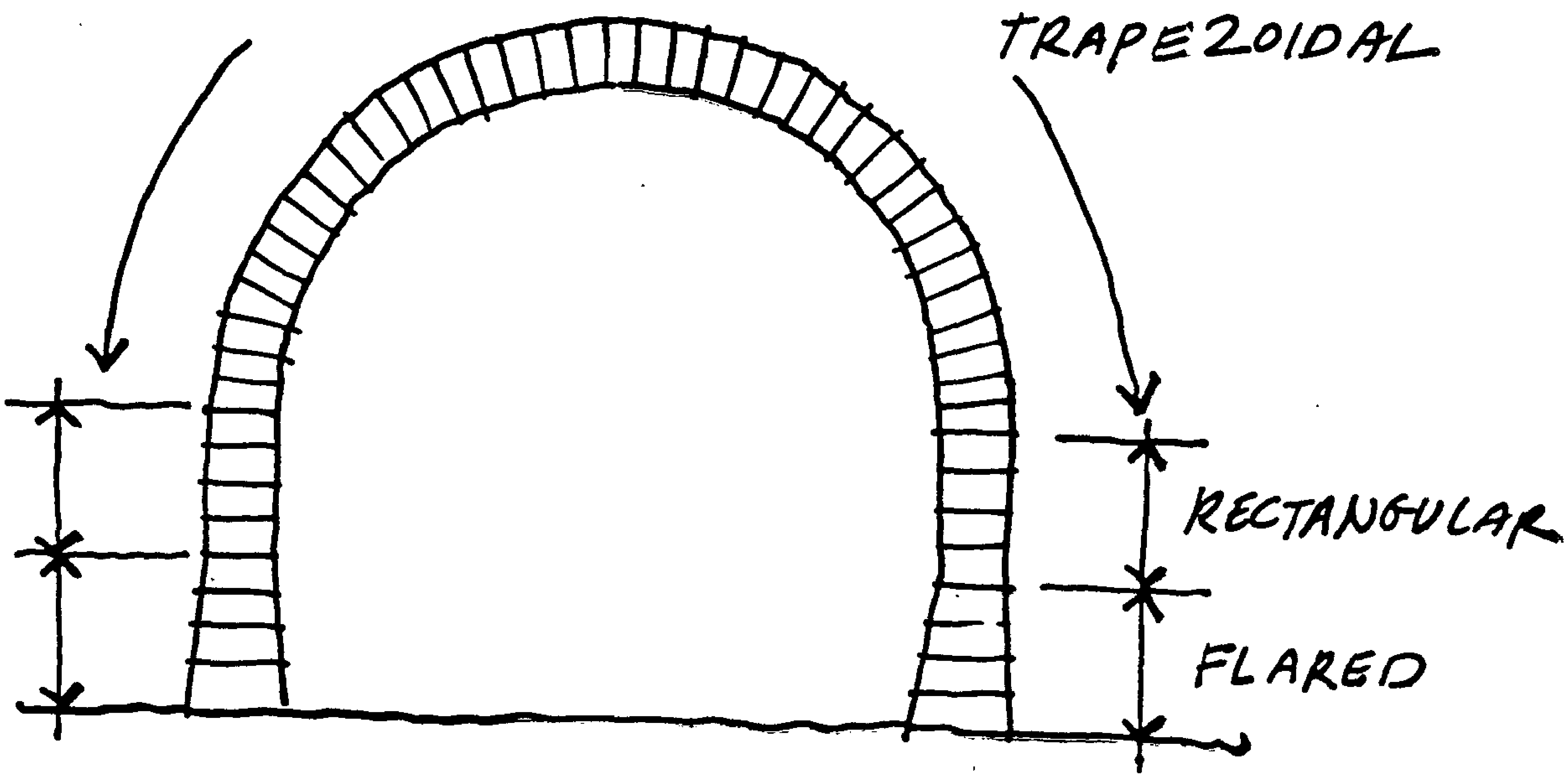
The stone arch is not tight to the inside rock face at the inside terminus of the arch. Therefore, there is a void space of unknown size between the arch stones and inside rock face. Rubble stones were visible at several locations where keystones are missing. However, it is not known if void spaces were filled with rubble or if loose rock has sloughed from the stone face above.

The stones are dense and sound, and all appear to be in good condition and capable of providing structural support. There is little or no evidence of cracking or deterioration due to effects of climate or loading.



SCHEMATIC PLAN
NOT TO SCALE

FIG 1



ARCH STONES

BASED ON FIG. #6
HISTORIC PHOTOS
(CLEMENSON 1990 - ATTACHMENT I)

FIG 2

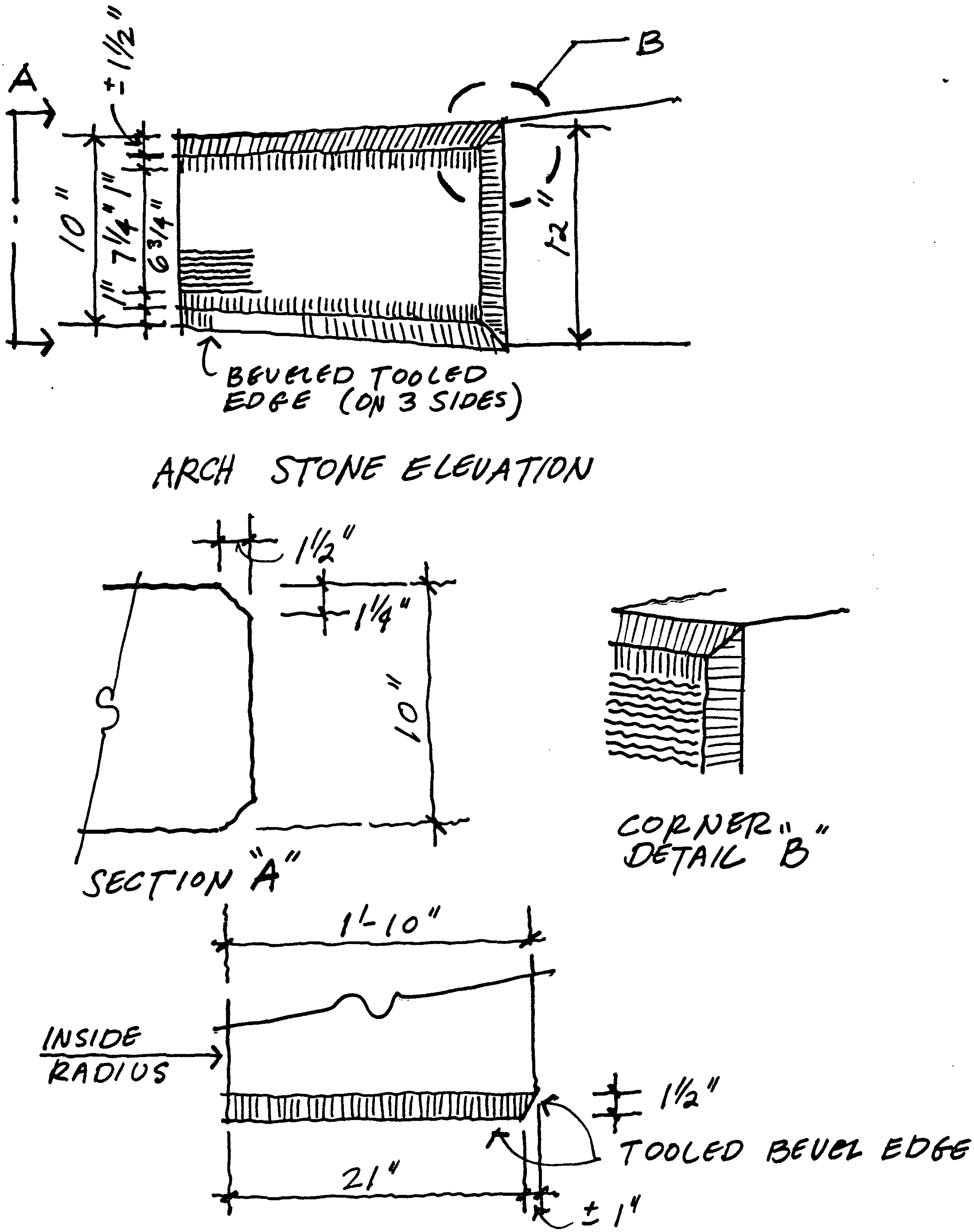

A
B
±1½"
10"
1" 7¼" 1"
6¾"
12"
BEVELED TOOLED EDGE (ON 3 SIDES)
ARCH STONE ELEVATION
1½"
1¼"
10"
SECTION "A"
CORNER DETAIL "B"
1'-10"
INSIDE RADIUS
1½"
TOOLED BEVEL EDGE
21"
±1"

FIG 3

The size of the stones vary, but are generally 10" to 12" thick, 21" wide and up to 3'-5" long. The weight of individual stones (using 165 lbs. per cubic foot) would be approximately 1000 lbs. each. Typical interior joints are 1/2"±.

Water weeps through the rock tunnel and collects in the joints of the stone lining. Water was observed on several occasions to be dripping through the stone joints. The stones and mortar are in a constant damp condition. The moisture has caused the loss of mortar in many joints and deteriorated the mortar in many other areas. The source of water is probably not controllable, as is the build up of moisture above and within the stone lining joints.

The coursing of the stone lining, visible at both tunnel entries, is uniform in width until a point well within the tunnel. At this point, six 6" wide tapered stones were placed to complete the aggregate "keystone". This detail is visible at the stone lining termination inside the tunnel.

2. East Stone Lining

The east stone lining stands without benefit of the stone entry facade or adequate retaining walls. As a result, many stones have been dislodged from their original position. (See figure 4.)

The existing grade at this entry is well above the original grade. Approximately three stones are below grade at this time.

The earthen cover at this arch cannot be retained in its present condition, and as a result, the cover is reduced to just a few inches at the center and to no earthen cover at the south side wall. At this location, the arch stones are exposed to view, weather and deterioration. (See figure 5.)

3. West Stone Lining

The west stone lining survives intact and in good condition due to protection from the extent entry facade. See Section II-B-2 for discussion of facade movement.

4. Entrance Facades

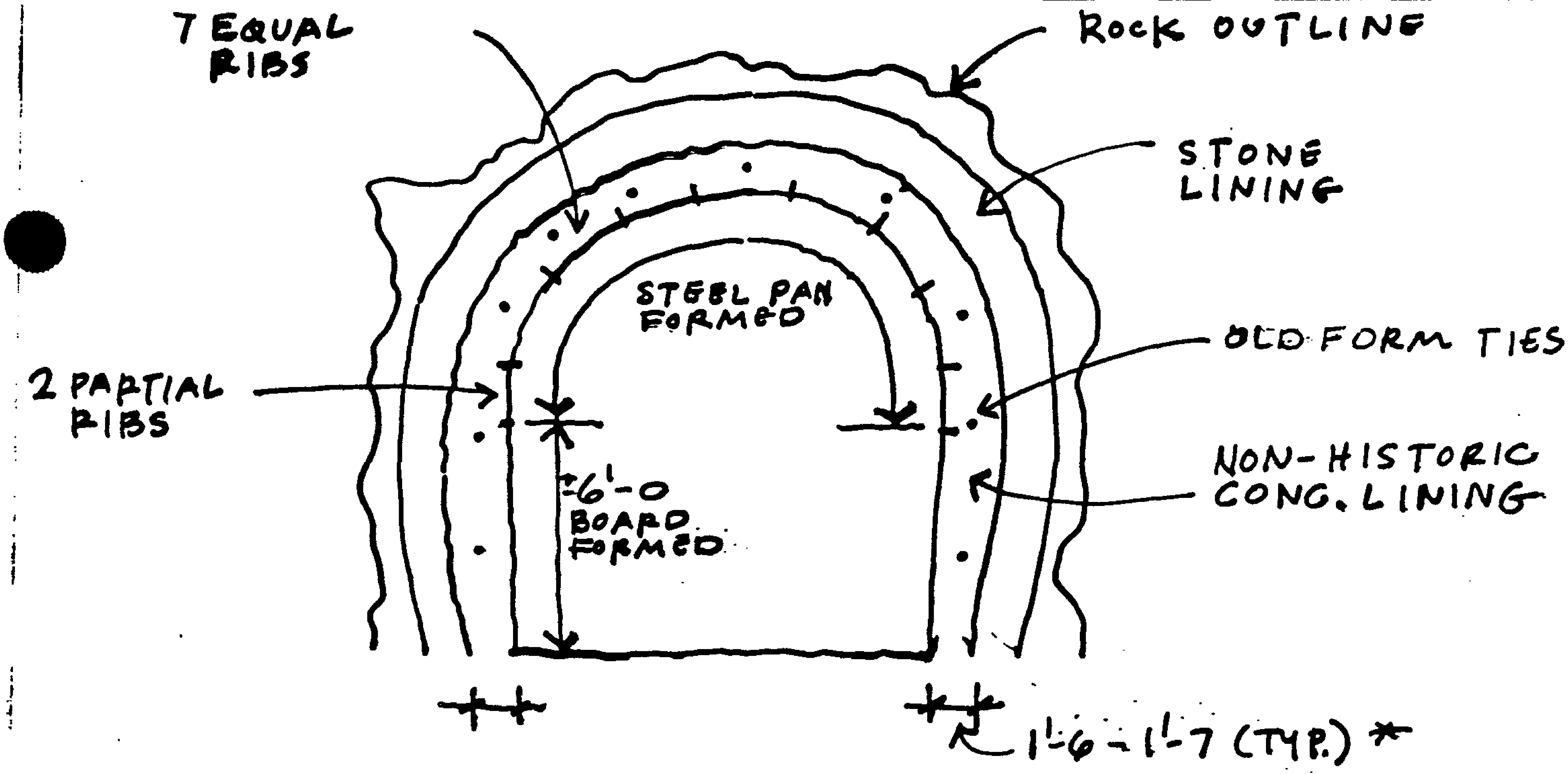
The cut stone entrance facades were the last element of the tunnel to be completed in June 1833. The tunnel has been described as a "Roman Revival style with a low relief lintel supported by Doric pilasters on each side." (Clemenson 1990:9)

The cut stone was reported to be a local Allegheny sandstone on the HABS drawings (undated).

Only the cut stone facade at the west end portal is extent. No historic photographs have been found which show the existence of the east portal.

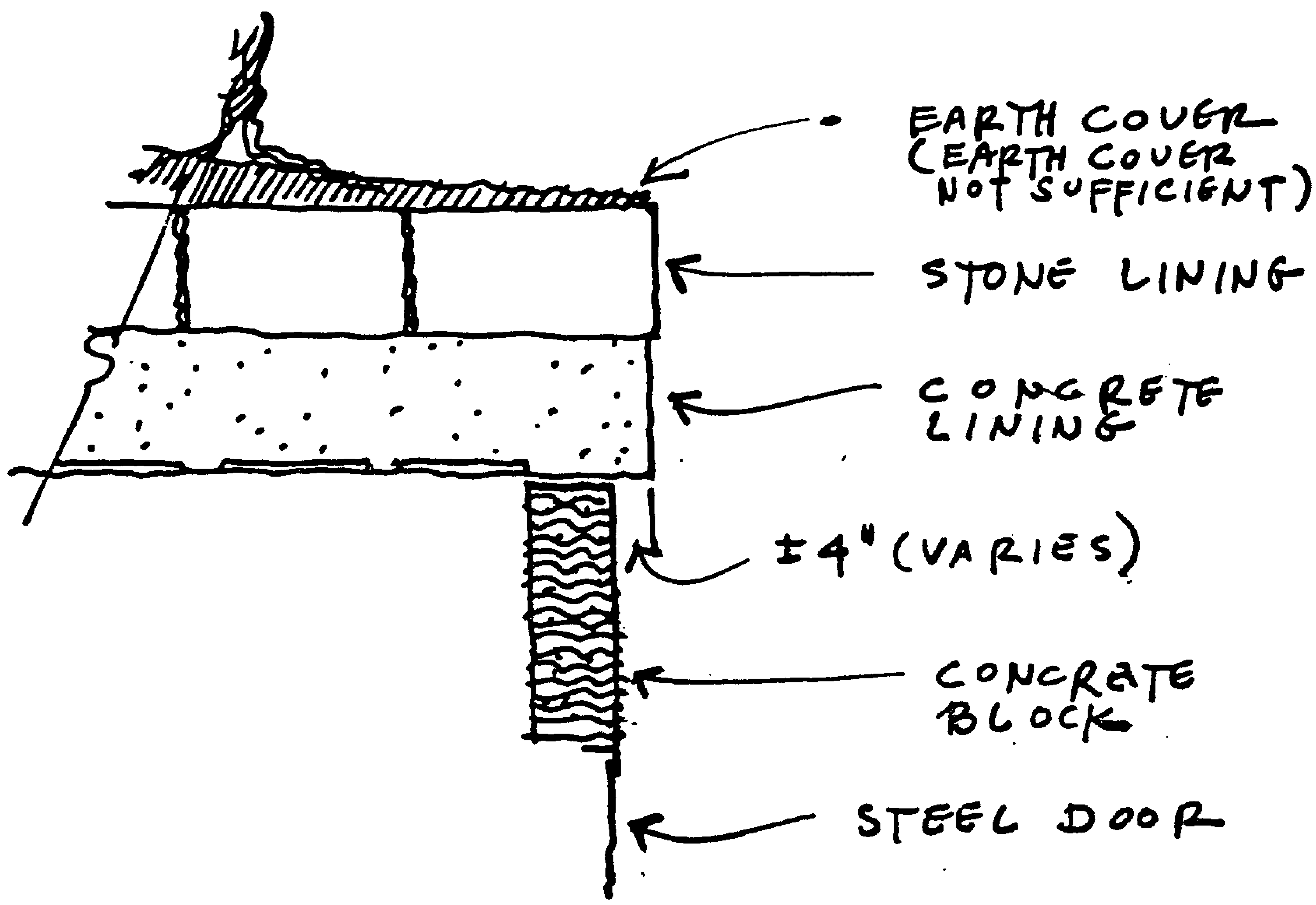
Recent archeological excavation at the north side of the east arch has revealed a portion of the north most doric column base. The dimensions from the stone arch match the dimensions of the west facade. (See figure 6.) Based on this facade remnant, it is very likely that the east facade was constructed similar, if not identical, to the west facade. (See Attachment III for Archeological Report.)

In order for the east facade to have been installed, extensive retainage would have been required on the south side at the base of the hill.



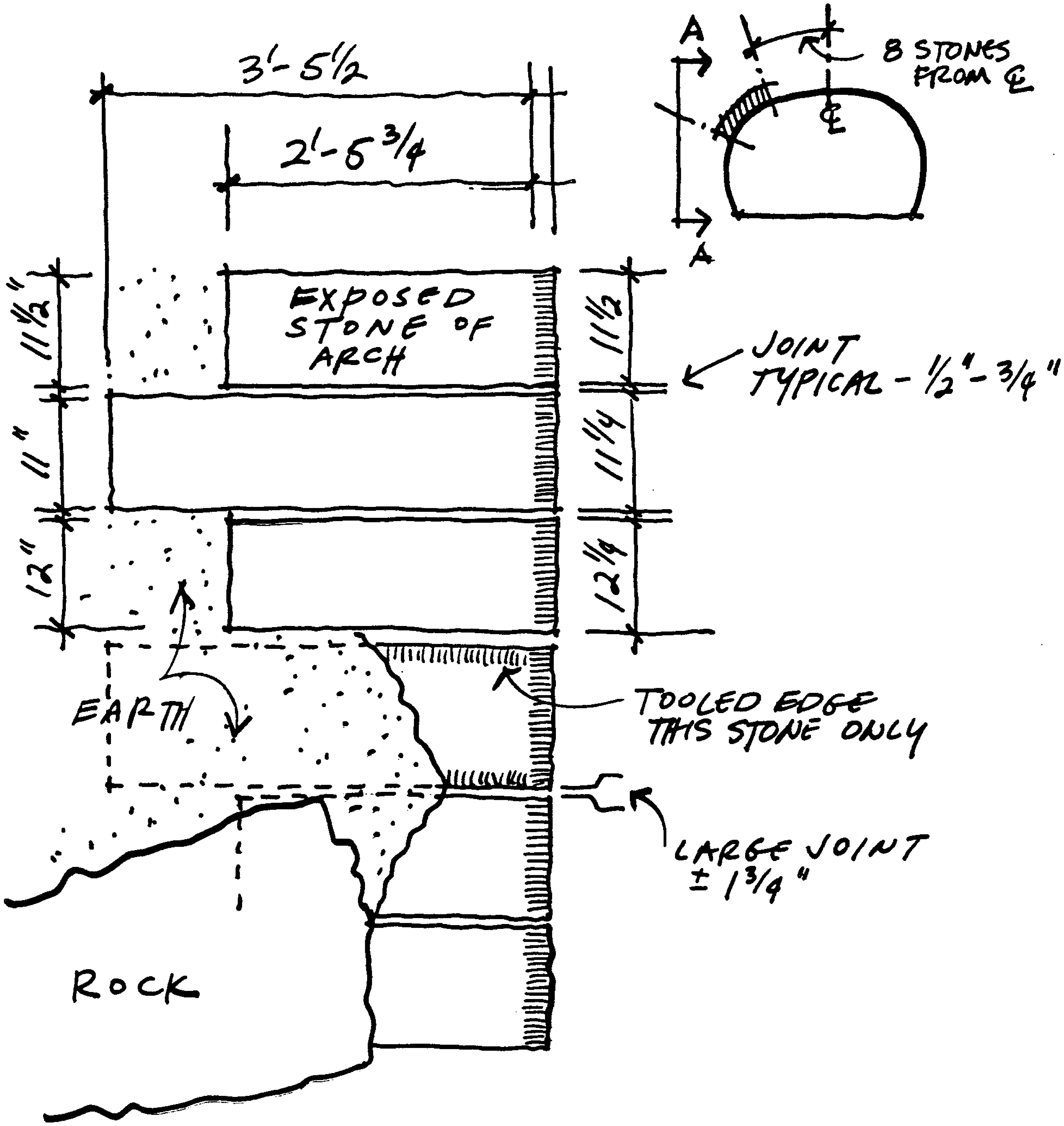
SCHEMATIC SECTION

* LINING IS THICKER @ EXPOSED EAST FACE VARIES TO 2'-4 WIDE



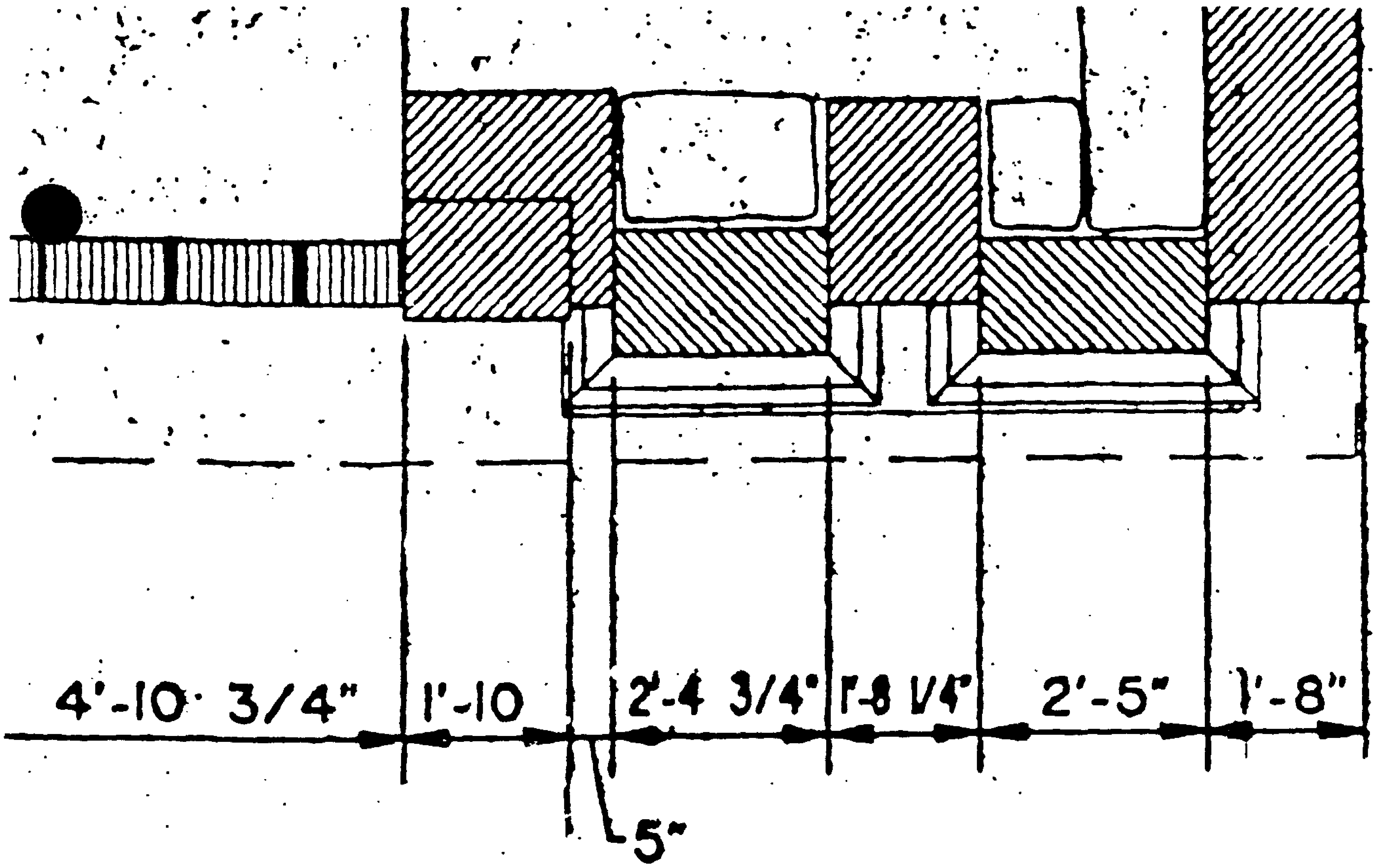
SECTION EAST PORTAL

FIG 4

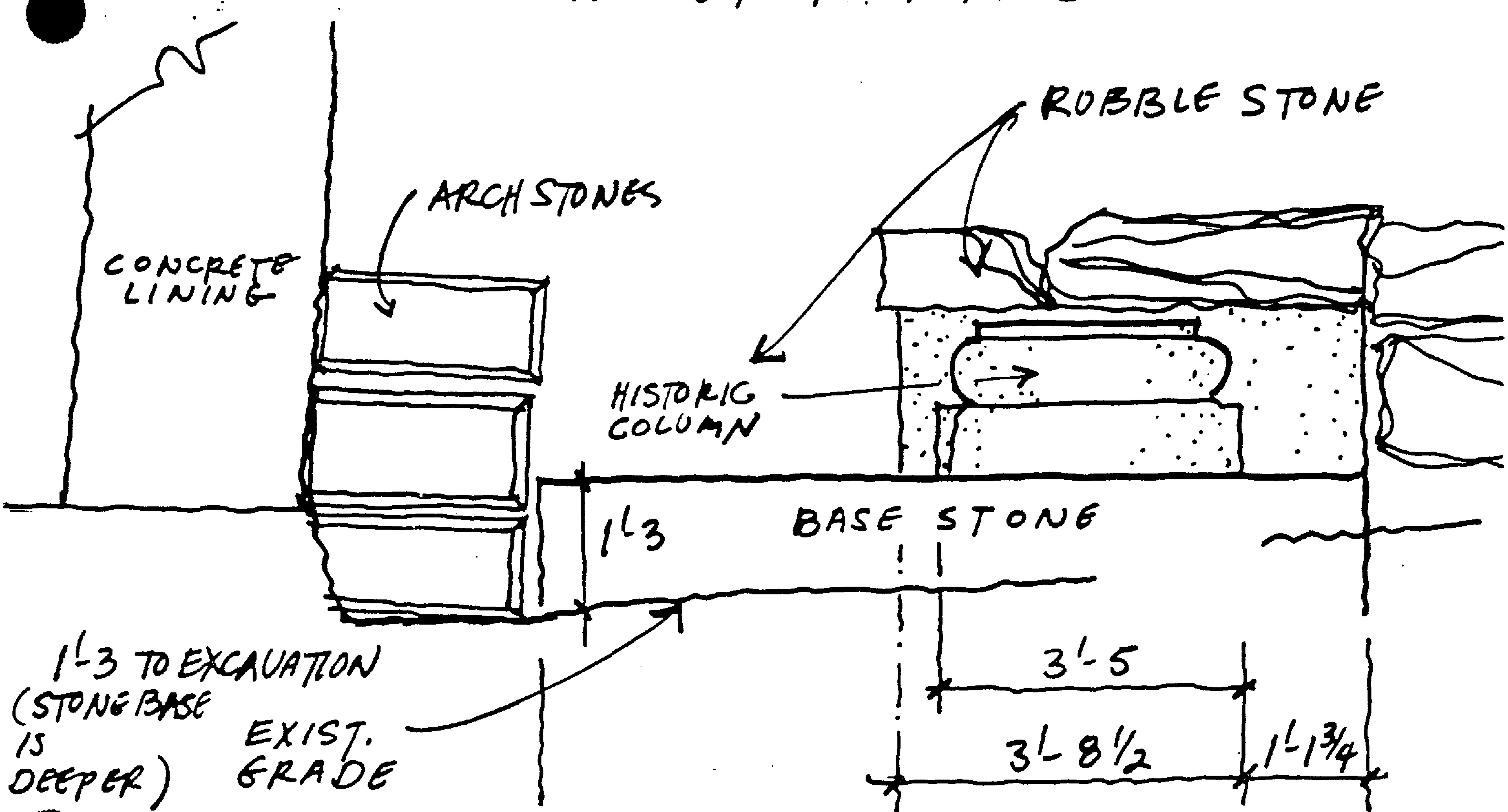


SOUTH SIDE PARTIAL ELEVATION
A-A
EAST PORTAL

FIG 5



COLUMN PLAN
WEST PORTAL



COLUMN BASE
EAST PORTAL

FIG 6

After the removal of the original cut stone facade, there was an 8'-7" gap between the remaining stone arch and the dry laid retaining wall. This gap has continued to increase due to erosion of the dry laid retaining wall. Presently, this gap is partially filled with rubble stone.

5. West Facade

The west facade is nearly intact when compared to the historic photographs. The craftsmanship, carving and tooling of the arch stones are evident in the dressed stone facade. The facade stones are precisely cut and laid with thin (±1/8") mortar joints. The stones are massive, especially the parapet stones, out of which the entire depth of the cornice was carved.

The front face of the facade was tooled to a smooth finish with both vertical and horizontal grooved accents. The side stones were hammered to a pebbled finish with a tooled, grooved edge band. The craftsmanship was excellent. The stones fit together tightly and the simple, refined details create an exquisite classical facade which has endured, virtually without maintenance, for 156 years.

The entry facade has the appearance of an architectural element. However, it serves as a retaining wall for the earthen cover over the stone arch lining. it is an elegantly detailed masonry retaining wall. It is not a complete structure which can be protected from moisture intrusion. It must be treated as a masonry retaining wall which is subjected to an uncontrollable source of moisture and the accompanying effects of freeze/thaw. (See figures 7 and 8.)

Despite the harsh environment, the facade has survived without extensive deterioration. The majority of the deterioration appears to be either manmade (broken cornice stones and graffiti) or due to plant growth in and around stone joints.

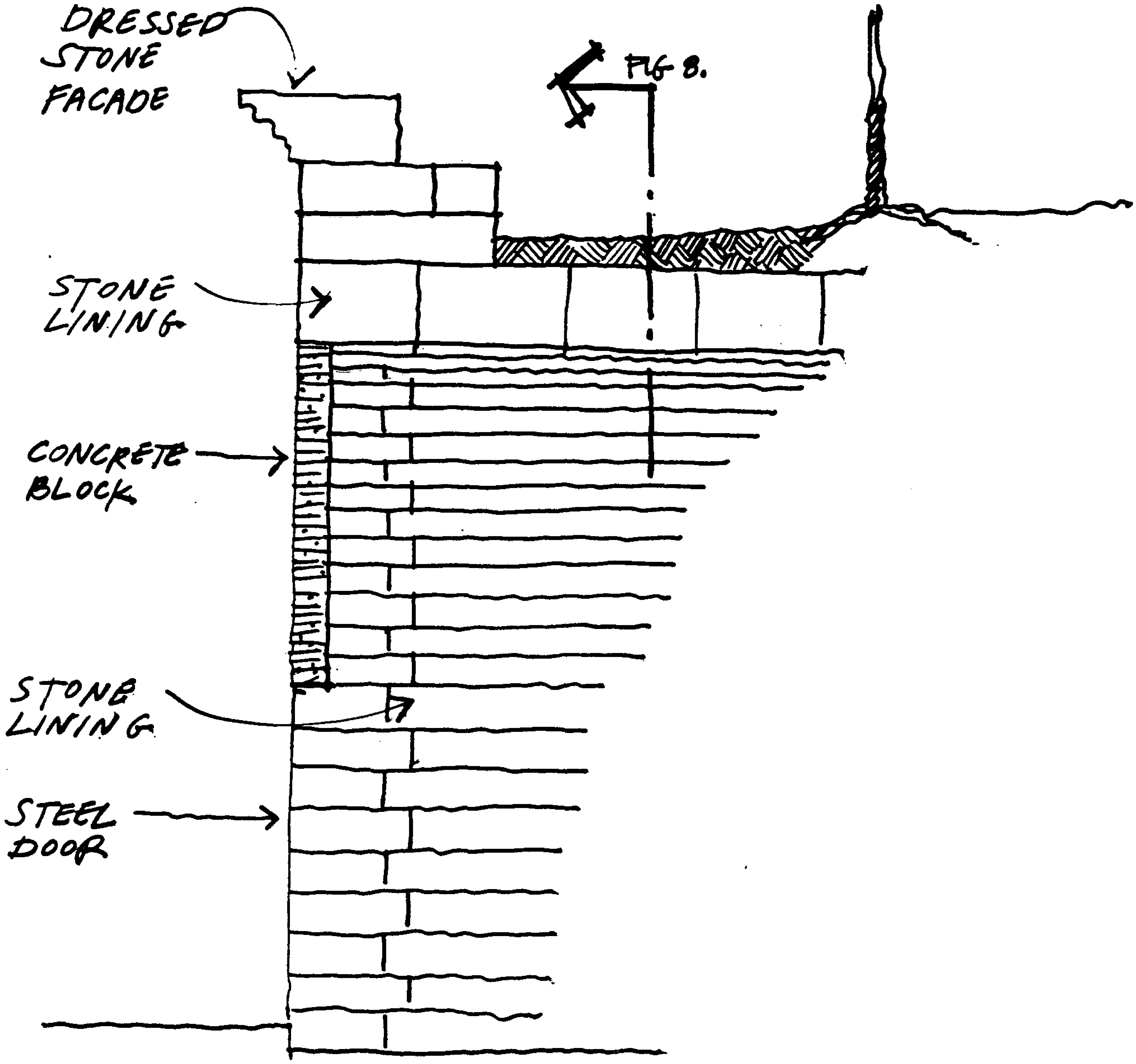
Evidence of stone movement appears at the column stones (which are laid vertically instead of horizontally as the rest of the facade). The two-piece columns have been dislocated approximately 1" at both of the southern columns. The source of the movement is not known, but may be attributed to freeze/thaw pressures, loads due to retainage or other hidden conditions. Also, it is not known if the movement is a new or an historic condition. The areas of movement should be monitored. (See Attachment II-B-2 for further discussion of the stability of this facade.

Black staining is evident on the facade stone. Evidence of staining is visible on the c. 1890 photos also.

Graffiti has been a problem for many years. Large painted letters are visible in a 1910 photograph. A 1920 photograph reveals much more graffiti on columns and the cornice frieze. The 1920 graffiti appears to be both painted and carved into the stone.

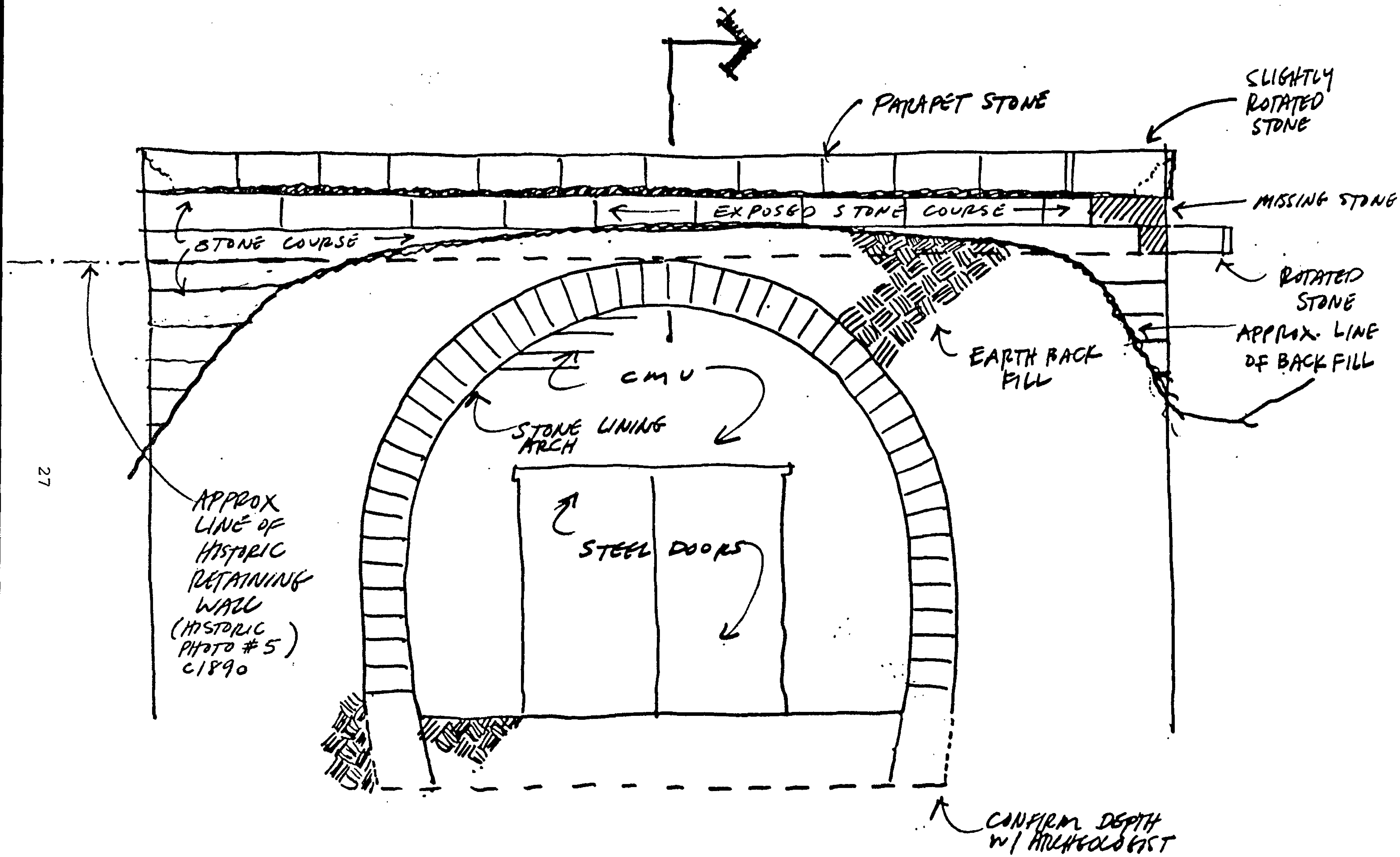
Vandalism also appears to have been a problem. The broken stone cornice appears to have been sheared off. The existing parapet stones are generally in sound, uncracked condition, except for the broken sections. Broken stones are first evident in 1890 (one broken stone). By 1895, the stones were broken in six locations. By 1910, only 5 stones at the parapet are not substantially broken.

Plant growth has consumed the west facade. Woody growth is prevalent at joints in the back and top of the parapet, on top of the columns and at many other joint locations. The plant growth creates deterioration by root growth, deterioration of mortar, movement of stones and water retainage and provides new sources of moisture infiltration.



SECTION @ WEST FACADE

FIG 7



SECTION THRU WEST END
(LOOKING WEST)

FIG 8

27

Present grade at the stone arch is covering up nearly three arch stones. These stones are the flared type according to an 1890 photograph and help to create the horseshoe shape.

Remnants of the dry-laid retaining walls are extant. However, they have failed extensively. The height of the original south retaining wall can be estimated by analysis of historic photograph #6. This nearly front-on view provides a good perspective to compare its relative height. The south retaining wall was approximately equal to the top of the stone arch. The wall was dry-laid in a very regular pattern with stones of uniform thickness.

A retaining wall on the north can only be seen in a c. 1910 photograph (photo #10). This photograph shows a wall much lower than the south wall, but of similar construction. It is not known if this wall is original since an 1895 photo (historic photo #7) shows a portion of the north column base to be partially covered. This same photo shows the south retaining wall as it intersects the facade south elevation. The retaining wall angles outward at the top of the wall.

B. Structural Stability

The following sections discuss the manmade structural elements of Staple Bend Tunnel. These include the dressed stone lining, the west end facade, the concrete lined portion of the east end and the dry laid retaining walls. All of these elements except the concrete lining were part of the initial construction done in the 1830's. The structural analyses pertain to conditions as observed and determined in the field investigation made in August, 1990.

1. Dressed Stone Tunnel Lining

The dressed stone tunnel lining begins at the facade at each end of the tunnel and extends into the tunnel for a distance of approximately 150 feet. The symmetrical shape at the west portal was used in establishing a model to calculate stresses on the stone lining within the tunnel. The computer results of the calculations are contained in Attachment IV. Loading diagrams illustrating how the load was placed and the results are also contained with the computer calculations. The basic structure was always assumed to be uniformly loaded except in one case that was run on the computer to look at the stresses with an unbalanced load. This was done primarily to see what field conditions would have had to exist to cause the lateral rotation of the tunnel lining at the east portal.

For the sake of this analysis the length of the lining stones was not a factor. The analysis was based on a one foot incremental length of tunnel. With the tunnel liner blocks interlocked, there will be some load transfer between adjacent liner stones but primarily the tunnel liner will function as a ring structure. The crown of the tunnel liner will pick up the vertical load component from the weight of the soil backfill covering the arch and the horizontal load component from the "equivalent fluid" load of the soil backfill along the sides transmitting them axially through the adjacent stones of the liner. The shape of the liner may be described as a horseshoe shape. The sidewalls will transmit the load down into the bedrock and pick up any lateral load from either the soil near the outside ends of the tunnel or the rock chinked backfill within the excavated rock portion of the lined tunnel. The structure is not generally capable of transmitting significant flexural moments in the structure because the joints, in particular, do not have the capability of transmitting tension stresses. Small moments are accounted for by the center of the resultant force passing through the individual blocks being offset from the centroid of the block.

The stone lining was treated as a uniform, symmetrically shaped tunnel with the crown forming a perfect circle. The cross section at the west end is the only location where this uniform cross section was measured. At other locations, the shape of the tunnel lining was found to be fairly uniform in curvature and this idealized analysis is felt to be sufficiently accurate to indicate the type of reactions taking place within the tunnel in the lining.

The loading conditions analyzed include the stone lining with no soil load whatsoever on it. The remaining loading conditions assumed uniform loading with backfill material level with the top of the arch, 3 feet, 5 feet, 10 feet, 15 feet, and 20 feet above the top of the arch. The analysis indicated that when the stone lining is in a stand alone condition, it is borderline unstable and should have restraint in the area where the arch crown comes into the tangent zone of the sidewall. This appears to be the area of the greatest eccentricity in the stress lines for this loading condition. Two loading conditions were also analyzed whereby the soil pressure on the exterior of the arch was increased in a passive way from the structure being able to deform and push into the soil backfill. This showed that the structure can and will move to relieve overstresses.

As the lining is loaded, both horizontally and vertically from soil backfill, it becomes more stable and it is a very good structure and well designed for taking the soil loads that presently exist at the two ends of the structure. Table No. 1 illustrates the maximum stress both perpendicular to the stone and shear stress that could exist in each different arch loading condition.

TABLE 1

Loading Conditions	Block	Interior Edge	Exterior Edge	Shear Stress (psi)
No Load	28	0	89	<1
H=0	28	120	0	13
H=0	19	0	108	<1
H=3'	28	109	5	16
H=3'	19	0	214	<1
H=5'	28	114	17	18
H=5'	19	0	282	<1
H=10'	28	127	52	22
H=10'	19	0	464	1
H=15'	28	147	79	26
H=15'	19	0	634	2
H=20'	28	158	116	30
H=20'	19	0	829	2
H=20 w/P.1	28	217	60	28
H=20 w/P.1	18	0	727	9
H=20 w/P.3	28	331	0	32
H=20 w/P.3	18	0	750	11

At the west end, there are fifty-five stones with half on each side of the centerline of the tunnel lining with the keystone being directly centered at the top. It was impossible to determine geologically the exact location that the tunnel lining went from being an earth backfilled structure to penetrating the rock formation of the hill. At this point, it will become a totally free standing arch not really carrying any external vertical loads except for occasional ceiling rock falls.

One observation that was made is that in the crown of the tunnel beginning at the west portal, the upper stones are all of uniform width similar to the shape of the stones visible at the facade of the tunnel. At approximately 40 feet into the tunnel, the upper stones change from being the full exposed width of about 10 inches down to a thinner stone of an estimated 5 and 1/2 inches. After this transition, there are 11 narrower stones across the crown with the center key stone being the thinnest and shortest element of the group. This would indicate that the larger stones were laid in an open cut method so that they could be placed from the outside from the top down and that the smaller inner stones were placed from the inside and had to be slid horizontally into place since the excavation of the rock is not sufficient for men to be above the arch to place these lining stones. It is apparent that a cribbing system was used to place these lining stones and once the full arch were in place, they were able to lower the cribbing and allow the structure to take the loads from the vertical weight of the lining.

The top profile of the crown of the tunnel appears to be very uniform. It is difficult to know whether all of the lining was shored at one time and then uniformly lowered in the same operation or whether the cribbing was removed as incremental lengths of tunnel lining were put into place and ready to take the load.

The conclusion to be drawn is that when any repair work is done, especially at the west portal, any over burden fill over the tunnel lining should be removed in uniform layers keeping the load on the lining symmetrical. If all of the backfill material is to be removed from the lining to reconstruct some of the dry laid retaining walls which will be discussed later, it would be appropriate to brace the inside of the tunnel to maintain the very uniform shape of the tunnel lining and not to take any chances on causing lateral deformations to the lining.

In determining the stresses on the individual stones, it was assumed that there was uniform bearing across the face of the stones. When any regrouting is done to fill the voids and to repoint the structure, it will be important for the grout to be applied in such a way as to fill the joint voids to maintain as uniform a load transfer as possible from one stone to the next. The least calculated load that is perpendicular or circumferential in any of the lining stones is at the crown (keystone) and is a compressive load of approximately 3100 lbs. per lineal foot which indicates there is a substantial axial load holding each one of the stones in place in addition to the significant shear stresses present in the structure.

In the crown at about Stations 0+58 and 1+03, individual stones have come out of the lining. These are discussed in greater detail in the geotechnical portion of this report (Attachment II). There has had to be load transfer around these individual void areas with higher stresses in the adjoining stones. Thus, if it is determined that stones are to be restored to these locations, the grouting and wedging will have to be done in such a manner so as to maintain the integrity of these replaced stones as well as the existing stones.

2. <u>West Facade</u>

The west tunnel entrance facade is described as a "Roman Revival style with a *low relief lintel supported by Doric pilasters on each side". The architectural aesthetics of the* facade are discussed elsewhere. Structurally the facade does not have the mass to stand on its own without help from other portions of the structure. The help that the facade appears to be receiving is significant from the frictional restraint of its bearing on the dressed stone lining. As a result of the interlocked nature of the lining, it would provide excellent frictional support along the joint line between lining and facade structure. In developing any of the structural conclusions, certain assumptions have to be made because the exact cross section of the facade is difficult to determine except for the visible evidence on the exterior of the structure.

For determining a stability analysis, it was assumed that the end wings of the facade are constructed in a uniform stone grid going from the top down to the bedrock. This gives the facade an overall height from bedrock to the top of the cornice of approximately 25.5 feet. The average depth of structure was taken as five feet. The lateral load on the structure is a function of the height and slope of the backfill. When constructed, the available information would indicate that for the first 15 $\pm$ feet from the back of the facade, the backfill was reasonably level before rising steeply (1-1/2:1) up the hill. The assumption was made that the backfill causes an active earth pressure of an equivalent fluid pressure of 40 pounds per cubic foot (pcf). The factor of safety against overturning at the outside edge of the facade is barely above 1.0 for this loading condition. Thus, the facade structure needs to be looked at as a "composite" structure. The structure would act in a composite manner from frictional resistance between the overlap of the blocks composing the facade and the overlap of the blocks composing the tunnel liner. Horizontal shear stresses would exist between the facade face and the tunnel liner. The calculations indicate that the facade is totally unstable along a line representing the joint of the facade facing and the tunnel liner without consideration of this "frictional" help.

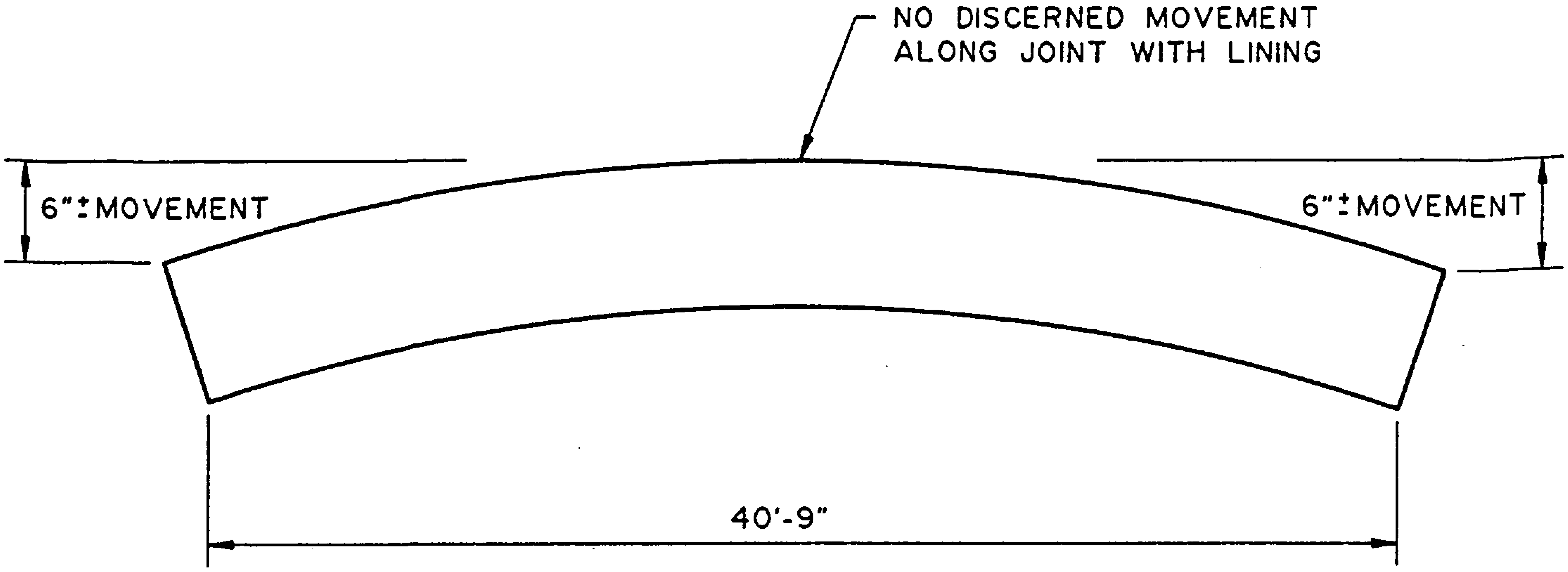
As the passive soil pressure builds up, the facade will yield and move laterally (outward) to relieve the pressure increase until the pressure is at or below the assumed active pressure. This cycle will continue over the life of a structure or until there is too much movement and failure occurs. Movement of the facade is discussed and illustrated in the following paragraphs. However, it is noted here that the missing east facade probably failed and fell over. The backfill at the east portal has sloughed away over the 100 plus years the facade has been missing. However, one can draw cross-sections with a facade similar to the west facade on the east end and see that the backfill would have risen on a slope of 2:1 almost from the back of the facade. This would greatly increase the assumed equivalent fluid pressure from 40 pcf to 60 pcf or higher and thus lead directly to failure.

The front face of the facade appears to be bowl shaped. The facade does not show evidence of any movement at the contact points with the stone arch lining and at the foundation stones. However, the farther you get from these two fixed zones, movement of the structure appears evident. The surveyed information along the front top of the cornice would indicate that the upper corners of the cornice could have moved in the range from 6 to 8 inches. It is difficult to confirm this as a fixed number because of the visible sliding and rotation of the top cornice stones. However, the 6 inch dimension is at the south cornice which appears to be fairly well in place and it is believed can be taken as a representative measurement of the distortion. A similar correlation can be made from the surveyed location of the back edge of the cornice. See Figure 9.

It is more difficult to draw the conclusion that there is this much movement from the surveyed location of the back edge of the second row. However, on these buried layers, when stones are out of sight, the exactness of the quarry dimensions begins to vary when it is not critical for the erection of the structure. Since the north corner stone of the second row is missing on the backside, it is impossible to establish a line across the full length of the structure for comparison as can be developed for the top cornice. The movement of the facade would indicate that this possibly took place when the full load was on the backside of the facade. The full load would have been on the facade when the dry laid stone walls came up to each end and held the dirt backfill on the backside of the structure. Since there has been significant deterioration of the dry laid stone walls adjacent to the facade, there has been a major amount of backfill material washed out with time from behind the structure which would relieve some of the soil load pushing against the back of the facade.

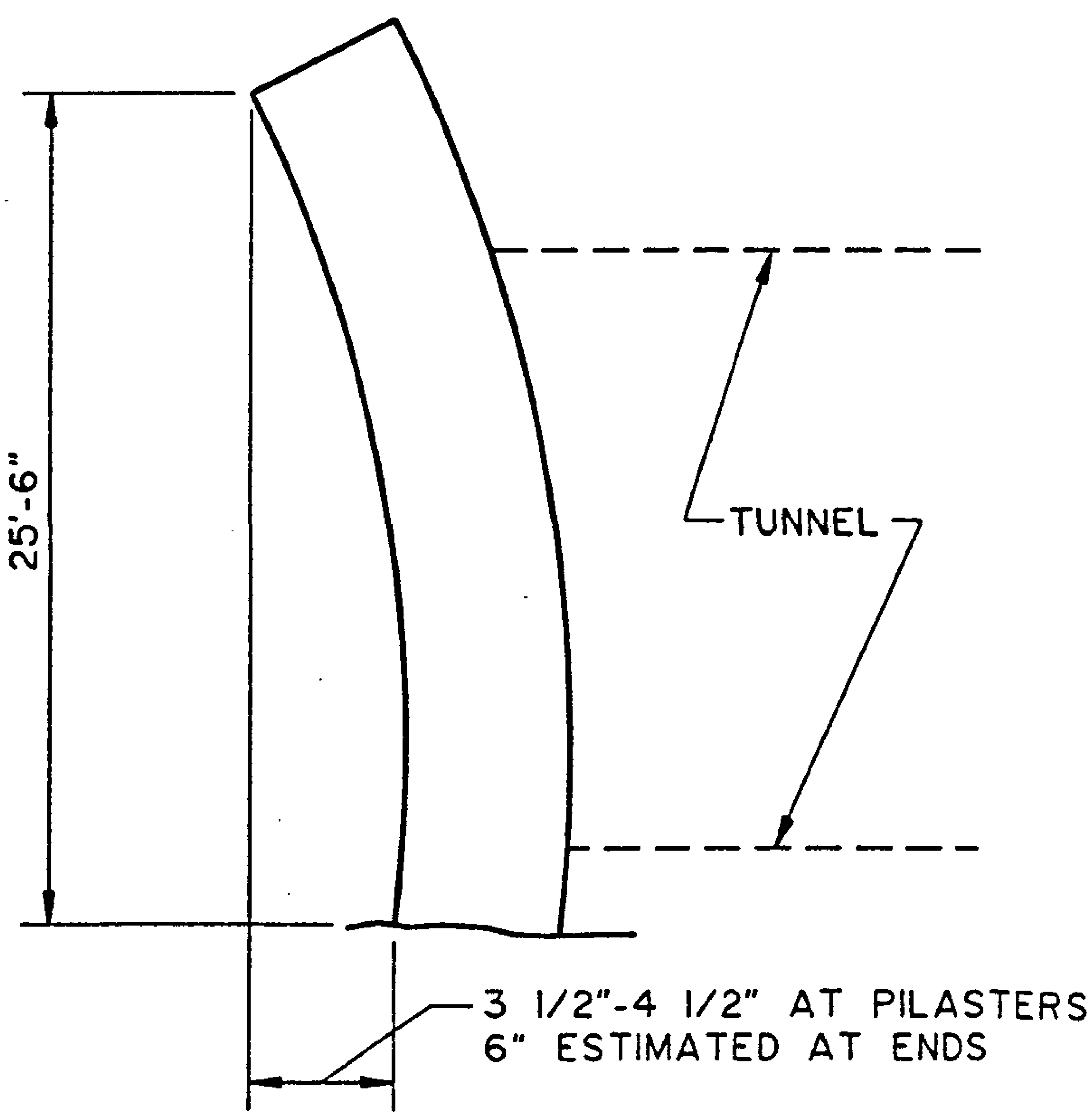
Vertical profiles were taken by the surveyors on the pilasters of the west facade to determine how much out of plumb they are. The north edge of the outside left pilaster and the right edge of the right side pilaster are out of plumb between 3 1/2 and 4 1/2 inches. On the pilasters adjacent to the arch, they are out of plumb between 2-1/2 and 3 inches.

There is evidence that the pilasters, particularly on the south side are horizontally displaced with respect to the front of the rest of the structure. The pilasters, particularly the one nearest the arch on the south side, show outward displacement of the pilaster stones independent of the remaining facade stones. Visually, they have moved independently of the other stones on a fairly uniform basis from the top to the bottom. This movement appears to have been more recent, probably in the last 50 or 60 years versus the 150 plus years since the structure was erected. One explanation for this movement is that at the time the structure was erected, dry laid stone walls were laid adjacent to the ends of both sides of the facade to an elevation equivalent to the top of the stone arch lining. These stone walls with the adjacent backfill would have provided lateral load against the ends of the facade. This lateral load possibly would have held the structure together more tightly and would have increased the friction forces holding the pilaster stones in place. With the deterioration of these dry-laid stone retaining walls primarily occurring since 1900 per the historic photographs, backfill material has been eroded out with time and weather. This activity may have relieved some of the lateral load holding the structure together very tightly. Thus, movement through root growth (root jacking)



PLAN AT TOP OF CORNICE

NOTE:
MOVEMENT IS DRAWN EXAGGERATED
TO ILLUSTRATE SIGNIFICANCE OF
MOVEMENT



ELEVATION AT END OF FACADE

FIGURE 9

of plant material that from time to time has grown over the face of the structure in the joints or through water (ice jacking) seeping into the joints and freezing, these pilaster stones have undergone some sort of jacking force that has caused them to move independently of the remainder of the facade.

One consideration would be that at the time the upper two or three layers of stone courses are removed on the north corner of the facade to repair the dislodged side stone, it might be possible to remove the column capitol to investigate the sequence of construction on lower layers of the facade structure with particular interest on the pilasters. This would give the engineers and the archeologists more information on how the structure was originally constructed. Future monitoring of movement then would have more basis of understanding. A program for regular monitoring of movement should be established. If measured movements of 6" vertically for out of plumb or 9" for horizontal curvature are made, then further remedial measures may need to be taken. An effort should be made not to increase lateral loads on the facade from any of the proposed stabilization measures.

3. East Portal Concrete Lining

The concrete lining of the east 50 feet of the east end of the stone tunnel lining appears to be in good condition. From the test pit dug at the westerly end, at the junction between the concrete lined portion and the dressed stone arch lining, it was determined that the wall is founded on the same sandstone bearing formation that supports the dressed stone lining.

It has been assumed that this concrete lining was installed in the early 1940's when the concrete water line was installed. However, we have not been able to document the exact year. The approximate thickness of the concrete lining varies with 18 inches about the minimum thickness observed. The exact details of construction of the lining are unknown. Also the size and spacing of reinforcing steel, if any, within the concrete lining is unknown but appears to be adequate since there is no evidence of major cracking in the crown. In a structure of this nature, it will act as a rigid structure and will support the load both in arch action and in flexural action. The stone lining is more flexible so that small movements will be more readily discernible as cracking in this concrete lining. On this type of structure, if there was significant deformation of the crown, flexural cracks would appear in a longitudinal manner running down the axis of the tunnel.

At the east portal, the rock outcrops at about 30 feet from the face of the east portal. It is fairly safe to assume that this is the location where the tunnel excavation penetrates into the rock formation and by the time the lining is at the 50 foot mark, the tunnel is back into the stable sandstone formation of the hill and thus the concrete lining is no longer needed to supplement that stable portion of the stone arch lining. The concrete lining will carry all the soil loads as well as the weight of the stone lining at the outer end of the tunnel lining in the area of the displaced stone and lining.

Though the concrete arch is probably reinforced, it is safer to assume that we should keep a symmetrical loading condition on this lining and not let loading conditions get significantly out of balance. It appears that after the dressed stone facade on the east end either was removed on purpose or failed (fell over) because of the soil load on the backside that this weakened the support structure for the arch. Soil erosion on the north side of the tunnel has been more severe than on the south side. Thus, an unbalance of the loading by just a small amount, say one or two vertical feet can significantly exaggerate the horizontal thrust of one side of the arch on to the lesser loaded side and can cause the horizontal translation of the arch and ultimately lead to failure of the stone lining. Soil cover of 2-1/2 to 3 feet should be reintroduced around the east portal structure to primarily act as an insulation blanket against repeated freeze thaw cycles which can tend to loosen and jack the lining stones around with respect to the concrete lining.

4. Dry Laid Retaining Walls

The dry laid retaining walls adjacent to both the east and west facades appear to have been properly designed. The large wall adjacent to the east facade has a measurable top thickness of approximately 5 feet at the highest point. In using the surveyed information, it is possible to approximate the front batter on the retaining wall. The minimum batter is about 1:8 with it increasing in some areas to as steep as 1:4.

Assuming a 1:8 batter on the backside, a dry laid wall of this configuration could be laid to a height of approximately 15 feet. To go higher than 15 feet would require increasing the dimension of the base.

At the east portal, the 8.5 feet of infill adjacent to the dressed stone arch lining has been added after the removal or failure of the east facade, at some point prior to 1890, based on the evidence from the historic photographs that are of record. There is no evidence of how extensive the dry laid stone wall would have been on the south side of the east portal. There is limited remnants of some stone wall at this location but not nearly as extensive as on the north side of this facade.

At the west portal, the evidence indicates that the dry laid stone walls approximated the top elevation of the arch based on views from the historic photographs. It is possible that it took a lot of time for fine grained material to be washed into these walls since they stood for a long period of time before failing. Once the fine particles filled the voids, frost action could have led to the dislodging of stones. With time and the increased runoff of water around the ends of the facade, erosion has taken its toll and has caused considerable deterioration in the dry laid walls immediately adjacent to the facade. It is also possible that some vandalism has taken place in these areas or that the rocks that fell have been incorporated into backfilling the area in front of the west portal.

In the historic photographs, evidence of the east wall of the Inclined Plane No. 1 one engine house is evident which would indicate a fairly large sized hole in the ground that has been filled over time with the construction of water lines, etc. in the area. The existing grade is 1 to 2 feet higher than the grade at the time the Allegheny Portage Railroad was in operation.

It appears that some reconstruction of the dry laid stone walls immediately adjacent to the facade is needed to help stabilize the erosion around the facade. Care will have to be taken during the time of excavation for the reconstruction of these stone walls along with an underdrain system to protect the main arch lining of the tunnel. A free draining imported granular backfill should be used in backfilling these stone walls to reduce the horizontal load buildup from the silts and sediments that will be washed down the hill from higher up the slope.

V. RECOMMENDATIONS AND COST ESTIMATE

A. East Portal

1. Stone Arch

The existing stone arch has been deformed due to unsymmetrical loading pressure and would not be stable without additional support. The individual stones are intact and sound. Pointing on the face joints is in good condition, although some cracks exist between the stone and concrete lining. All joints exposed to the earth need repointing.

2. Concrete Lining

The non-historic concrete lining is poured adjacent to the stone and conforms to dislodged stone. This lining provides structural support for the stone arch. Removal of this concrete lining is not recommended due to potential damage to the historic stone and it represents an example of a technological change.

3. New Retaining Wall

A new retaining wall is required to provide for proper site drainage, to prevent continued sloughing, for stabilization of the east portal and to provide sufficient earth cover over the (now exposed) historic arch stones.

The retaining wall will also provide a setting for the stone arch and will provide a more complete picture of the relationship of the facade element. For example, the dry laid wall at the north side of the entry represents a non-historic condition, dry laid retaining walls were never in that location and never would have been adjacent to the arch lining. The new retaining wall can be a variety of shapes and materials.

The basic requirements are:

a. Provide minimum cover of 30" at the crown to alleviate freeze/thaw deterioration.
b. The wall needs to be the historic width to provide sufficient retainage.
c. Materials should reflect non-historic materials and should not compete with the historic fabric.

Three design alternatives have been provided:

a. Elevation I Option - A stepped concrete form of historic width and of a variable height which allows for minimum earth cover above the stone arch and provides a simple, modern image without excessive detail.
b. Elevation II Option - Concrete retaining wall of historic dimensions with formed reveals which "ghost" historic proportions.
c. Elevation III Option - Concrete retaining wall of historic dimensions, plain facade.

Other Considerations:

a. Signage indicating the portal and date should be included.
b. The concrete should be sandblasted to help it to blend into the natural setting.

4. Historic Column Base

The remnant of the historic column base supports the conclusion that the East Facade had a stone facade similar to the West Facade. This remnant should be preserved and incorporated into the required retaining wall. The remnant should be located in its historic position. Portions of the historic base not visible due to adjacent grade would be removed to allow for the new retaining wall footing placed on bedrock.

5. Stone Retaining Walls

Existing dry laid walls should be preserved and stabilized. If additional retainage is required at the historic walls, they should be constructed of similar methods and stone.

The existing stone has a black patina. New stones should be of the same cut, size, shape and material, but should have a natural finish and be allowed to gain patina naturally.

Where new stone retaining walls are required, they will have a concrete structural support and a stone veneer.

6. Vegetation/Drainage

Vegetation and drainage shall be treated as recommended in the Civil and Geotechnical sections.

7. Entry Gate

The existing concrete block and steel doors should be removed. The new infill material should be non-dimensional and non-structural in appearance.

Three options are described:
Options A & B - Solid, opaque infill and doors which provide security and cold weather protection. Steel plate wall and doors are recommended.
Option C - Open bars which provide visual access but prohibit entry and control animals. A painted steel tube frame is recommended. The grill will follow the contour of the arch and when viewed from a distance, the shape of the arch will be visible.

Since the open grill will not provide protection from the cold, a removable insulated wall will have to be installed during the winter. The insulated wall should be panelized to facilitate removal and storage and should be as lightweight as possible.

An alternative to the removable insulated wall may be the use of a non-reflective "lexan" plastic, permanently attached to the grill.

Regardless of which option is installed, the new door and infill should be set back from the stone entry to allow a more accurate picture of the tunnel appearance. Setback should be a minimum of 3'-0" (to allow a visitor to stand within the tunnel). The setback should not exceed a depth of 10'-0".

B. West Portal

1. Stone Facade and Stone Arch

Recommendations for the historic West Facade are directed towards its preservation and structural stability. Control of drainage and soil pressure are the primary concerns along with resetting displaced facade stones. The control of drainage and soil pressure will be discussed in Section IV-B-2.

The dislodged parapet stones should be marked as to location and removed to allow for reinstallation of lost and rotated stones. Historic setting methods and construction should be carefully documented during disassembly. Samples of historic mortar remnants should be saved and evaluated. Evidence of pinning or other methods of connection should be examined. The disassembly process and exposed conditions should be fully documented by photographs and field sketches for a permanent record.

After all of the stones necessary for reconstruction are removed, the historic stones should be laid to their historic locations. Means of setting the stones will be determined by the results of information gained during disassembly.

If mortar is used to set the stones, it shall be compatible with the adjacent masonry system in strength, texture and color. All reinforcement shall be stainless steel. Mortar joints shall be the same size as historic joints.

The historic parapet stones (with broken edges) are to remain.

Pointing on the face joints of the facade and stone lining are generally in good condition. However, limited pointing will be required where there are cracks or missing mortar.

The joints of the parapet stones (horizontal and vertical) should be either pointed or filled with sealant with a fine sand pressed into the sealant.

The black staining of the stone is quite old and does not appear to be damaging the stone. It is not recommended to clean off the stain at this time. The staining should be monitored to determine if it is deleterious to the stone.

Historic graffiti and graffiti carved into the stone shall remain. Painted graffiti should be removed after sample methods of cleaning have been evaluated to determine impact on stone and final appearance of the "cleaned" area versus areas not cleaned. The entire facade should not have a general cleaning.

As described in the structural analysis, the facade walls are out of plumb in both a vertical and horizontal plane and the column stones have been displaced from the rest of the stone face. Since it is not possible to determine when this movement occurred, it is recommended that a system be installed to allow for monitoring. Monitoring should occur on a semi-annual basis for the first two years and annually thereafter.

2. Retaining Walls

It is recommended that new retaining walls shall be provided only as necessary to control drainage and soil pressure, prevent further erosion and to allow for the exposure of the north and south column bases.

The new retaining walls shall not increase soil pressure on the facade (which would happen if the retaining walls were built to their historic height). Retaining walls will have to be provided on both the north and south sides. Retaining walls will be constructed as described for the East Portal.

3. Vegetation/Drainage

All vegetation in the stone joints shall be eliminated. Where necessary, the stones will be repointed.

Reference the Civil and Geotechnical sections for other vegetation and drainage recommendations.

4. Entry Gate

The existing concrete block at steel doors should be removed. New infill shall be as described for the East Portal.

The entry gate should be set back within the tunnel a minimum of 3'-0" (to allow the visitor to stand inside the tunnel and to view the first joint of the stone lining). The setback should not exceed the depth of the stone facade.

Recessing the gate (and insulated panels) exposes a portion of the stone lining to cold weather and may have a negative effect on the exposed stones. Holding the recessed to the depth of the facade may help to control moisture penetration and the effects of freeze/thaw.

5. Water Structure

The existing concrete structure is located on the historic Engine House foundation. The structure is obviously non-historic and intrudes into the historic scene and inhibits the view of Incline 1 from the tunnel entry.

The structure is presently owned and utilized by Bethlehem Steel. Modifications to this structure may be possible if an agreement is worked out with Bethlehem Steel. See Section VII-A-1 for further discussion.

C. Stone Lining

Preservation of the historic stone lining will require repointing and moisture control. Additionally, loose or displaced stones may require shimming. Pointing materials shall be visually and physically compatible with the existing masonry. Shims shall be non-corrosive. Mortar samples will be required to determine strength and composition of repointing mortar.

If missing stones are to be replaced, new stone to match the existing sandstone should be installed. The stone should be cut and tooled to match the existing. The material should be natural and allowed to gain patina naturally.

D. Summary of Estimated Costs

STAPLE BEND TUNNEL
ENGINEER'S COST ESTIMATE
April, 1991
S&G No. 90783-32

Exterior West Portal	$ 93,900[1] [2]
Interior Tunnel	
Priority 1 (3)	$ 58,700
Priority 2	92,500
Priority 3	52,600
Exterior East Portal	$134,900[2]
Other Items	
General Contractor Expenses	75,000
Construction Access Road Improvements	24,700[4]
Lower Water Vault	9,600
Sub-Total	$541,900
Allowances for Remote Site (25%)	135,500
Preliminary Estimated Construction Cost	$677,400
Project Contingency (30%)	203,200
Total Estimated Construction Cost with Contingency	**$880,600[5]**

NOTES:

1. Based on quantities and unit costs listed on the following pages.
2. Assumes all closures will cost the same.
3. Priority 1 - Required for public safety if tunnel is opened.
   Priority 2 - Optional item for public safety.
   Priority 3 - Not required for public safety but items for completing the interior.
4. Assumes construction access up Inclined Plane No. 1.
5. Does not include any allowance for electrical, signing, or other interpretive improvements, any extra landscape amenities, nor any design and construction administration services.

DETAILED COST BREAKDOWN

EXTERIOR WEST PORTAL

1.	Clear & Grub	L.S.	= $ 5,000
2.	Remove Existing Closure	L.S.	= 2,000
3.	Remove & Reset Cornice Blocks	15 @ $400	= 6,000
4.	Clear Rubble	100 C.Y. @ $20	= 2,000
5.	Clean Graffiti	L.S.	= 2,000
6.	Shore Tunnel Lining	600 S.F. @ $10	= 6,000
7.	15" Culvert	30 L.F. @ $50	= 1,500
8.	Flared End Sections	2 ea. @ $150	= 300
9.	Excavation	375 C.Y. @ $25	= 9,375
10.	Granular Backfill	170 C.Y. @ $25	= 4,250
11.	Other Backfill	135 C.Y. @ $25	= 3,375
12.	Waterproof Membrane	300 S.F. @ $1	= 300
13.	Grouted Stone Pan	150 L.F. @ $40	= 6,000
14.	Dry Laid Stone Walls	130 C.Y. @ $100	= 13,000
15.	Resurface Entry	90 tons @ $20	= 1,800
16.	Revegetate	L.S.	= 5,000
17.	Open Grill & Gate w/Panelized Infill		= 26,000
	Sub-Total		**$ 93,900**

EXTERIOR EAST PORTAL

1.	Clear & Grub	L.S.	= $ 6,000
2.	Remove Existing Closure	L.S.	= 2,000
3.	Clear Rubble	100 C.Y. @ $20	= 2,000
4.	Clean Top of Existing Wall	L.S.	= 1,000
5.	12" Storm Sewer	110' @ $40	= 4,400
6.	Flared End Sections	2 ea. @ $150	= 300
7.	Storm Inlet	2 @ $1,000	= 2,000
8.	Manhole	1 @ $1,200	= 1,200
9.	Excavation	770 C.Y. @ $25	= 19,250
10.	Granular Backfill	320 C.Y. @ $25	= 8,000
11.	Other Backfill	230 C.Y. @ $25	= 5,750
12.	Dry Laid Stone Wall	20 C.Y. @ $100	= 2,000
13.	Facade Concrete	55 C.Y. @ $400	= 22,000
14.	Retaining Wall Concrete	45 C.Y. @ $400	= 18,000
15.	Stone Veneer	430 S.F. @ $10	= 4,300
16.	Rock Anchor Bolts	50 L.F. @ $30	= 1,500
17.	3' Wide Concrete Pan	110 L.F. @ $20	= 2,200
18.	Resurface Entry	50 tons @ $20	= 1,000
19.	Revegetate	L.S.	= 6,000
20.	Open Grill & Gate w/Panelized Infill		= 26,000
	Sub-Total		**$134,900**

DETAILED COST BREAKDOWN (Cont.)

INTERIOR TUNNEL

	Section	Priority [1]	Cost
1.	West Masonry-Lined Section (150 feet)		
	a. Replace Lost Blocks	1	$ 3,500
	b. Repointing	1	11,500
	c. Tunnel Invert Cleanup	3	3,500
2.	Bedrock Tunnel Section (600 feet)		
	a. Tunnel Crown		
	(1) Wedging and Baring	1	20,700
	(2) Dowels	1	23,000
	b. Tunnel Walls		
	(1) Break Back Overhangs	2	69,000 [2]
	(2) General Rock Removal	2	20,000
	(3) Sealing Lower Red Sandstone	3	13,800
	c. Tunnel Invert Cleanup	3	13,800
3.	East Masonry-Lined Section (100 feet)		
	a. Repointing	2	3,500
	b. Tunnel Invert Cleanup	3	2,300
4.	East Concrete-Lined Section (50 feet)		
	a. Tunnel Invert Cleanup	3	1,200
	Sub-Total Priority 1		58,700
	Sub-Total Priority 2		92,500
	Sub-Total Priority 3		34,600
	Tunnel Invert Trail Surfacing Priority 3 (From Next Page)		18,000
	Total Interior		**$203,800**

NOTES:

(1) Priority 1 - Required for public safety if tunnel is opened.
Priority 2 - Optional Item for Public Safety.
Priority 3 - Not required for public safety but items for completing the interior.

(2) Break back overhangs option used.
Deduct $56,500 for steel shoring post option.
Deduct $61,800 for timber shoring post option.
Deduct $48,300 for fenced path option.

DETAILED COST BREAKDOWN (Cont.)

GENERAL CONTRACTOR EXPENSES

Mobilization/Demobilization	$ 30,000
Field Office	25,000
Bond & Insurance	20,000
Sub-Total	**$ 75,000**

CONSTRUCTION ACCESS ROAD IMPROVEMENTS

Roadbase on Incline No. 1	500 tons @ $20	$ 10,000
Blading	L.S.	2,000
Removal of Base Course	500 @ $10	5,000
Revegetation	L.S.	2,000
Clearing	L.S.	2,500
Blade Road Around Hill	1600 L.F. @ $2	3,200
Sub-Total		**$ 24,700**

ARCHITECTURAL INFILL TREATMENT

Closure Option C with Infill	
Open Steel Grill & Gate	$ 16,000
Removable Panelized Infill (Aluminum - Infill 2)	10,000
	$ 26,000
Options A & B	
1/4" Solid Steel Plate Infill with Doors	$ 13,000

MISCELLANEOUS ITEMS

Tunnel Invert Trail Surfacing		
900' x 20' = 18,000 S.F. @ $1		$ 18,000
Lower Water Vault		
Remove Concrete	20.74 C.Y. @ $100	$ 2,075
New Top Slab	8.33 C.Y. @ $500	4,165
Manhole Cover	L.S.	360
Regrading	L.S.	1,000
Overflow Detail	L.S.	500
Vent Piping	L.S.	500
Misc. Work Inside	L.S.	1,000
Sub-Total		**$ 9,600**

VI. DRAWINGS

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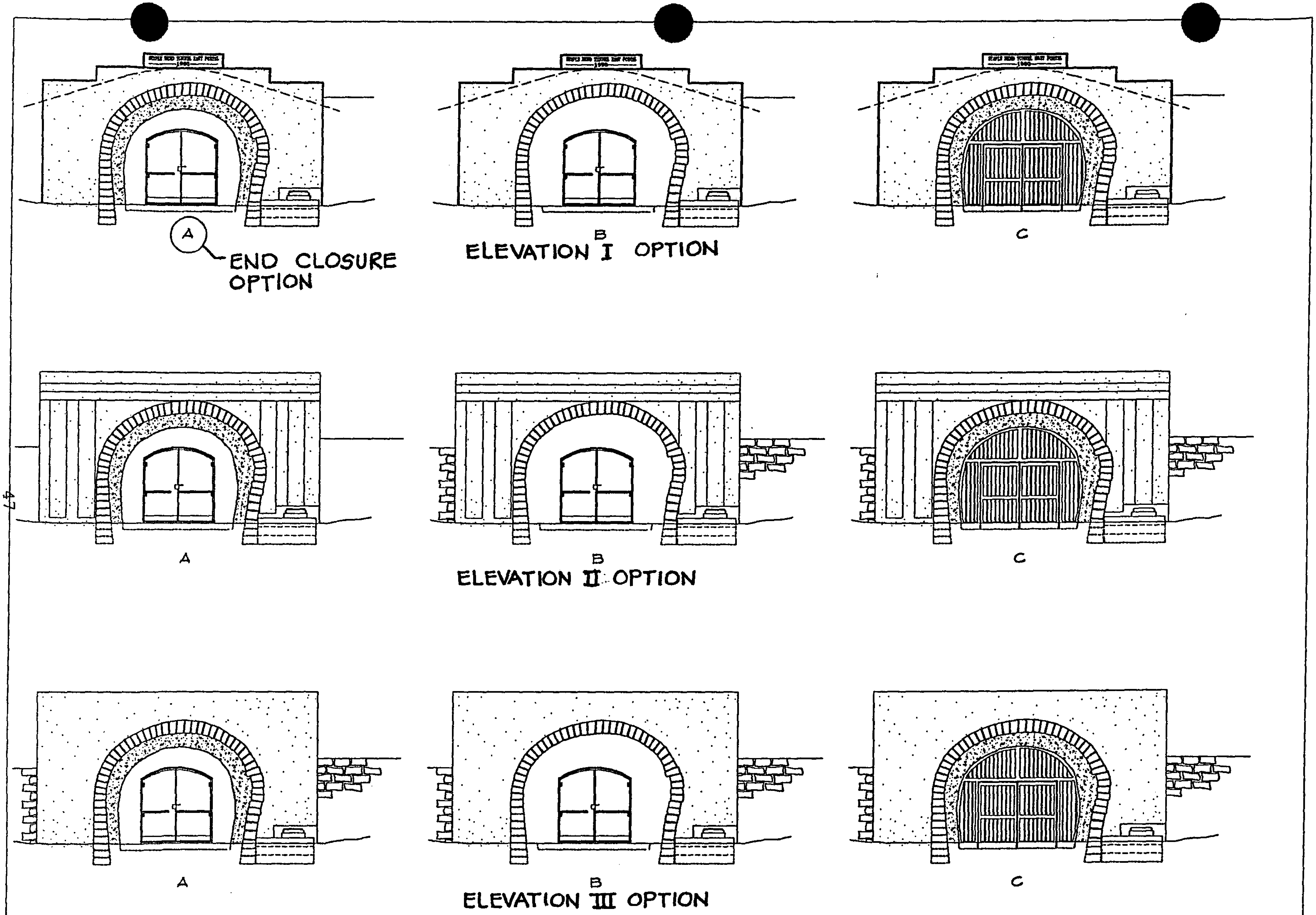
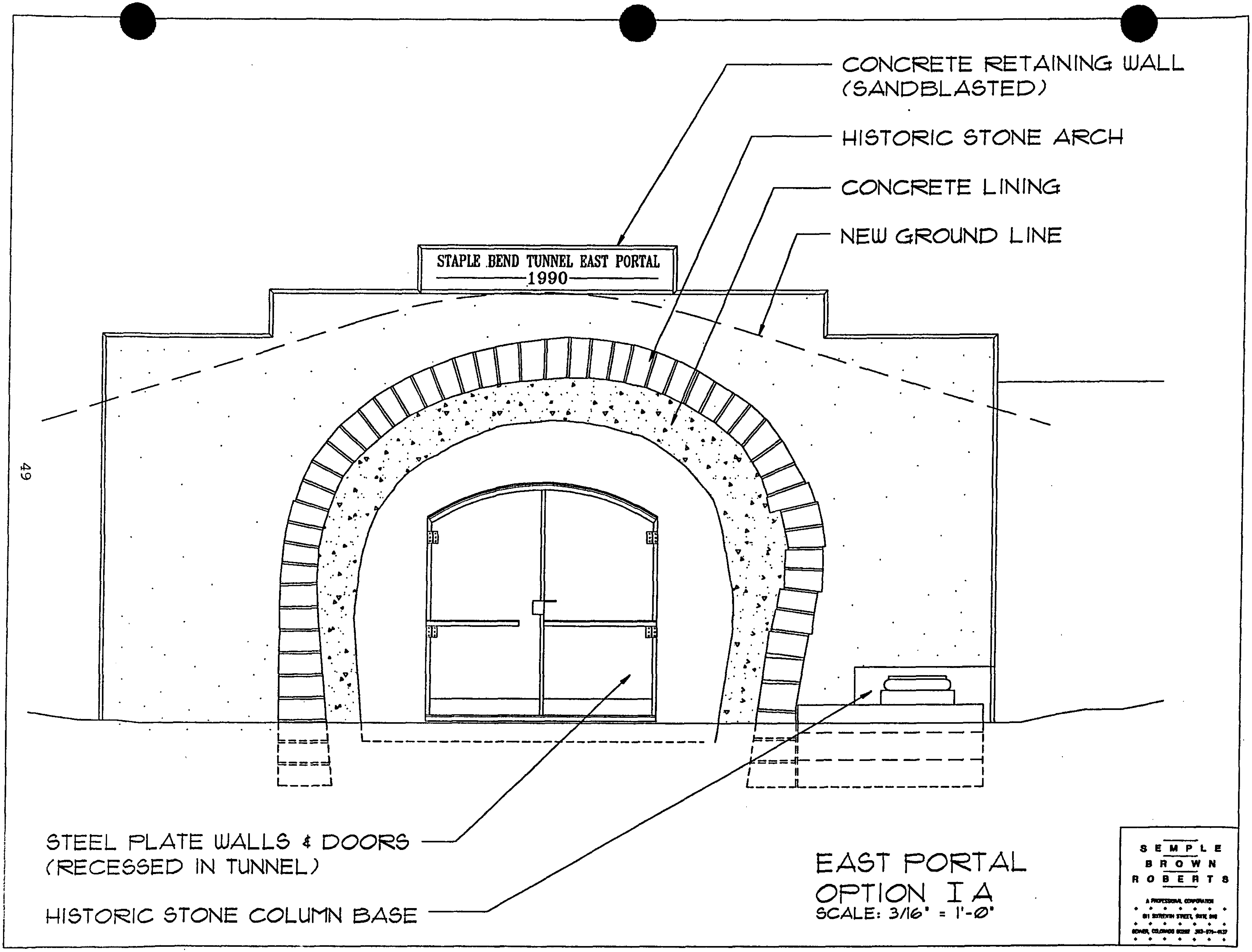
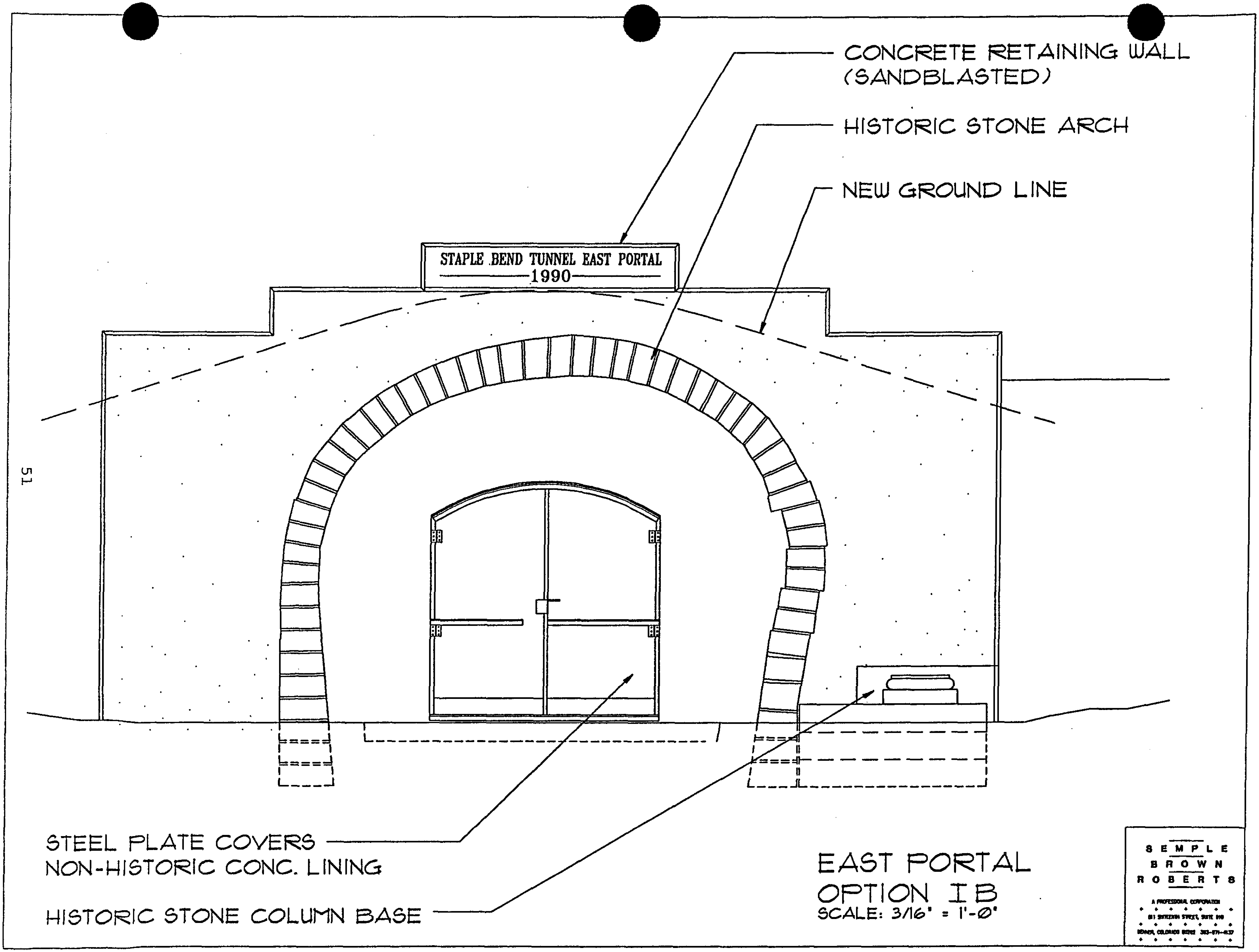
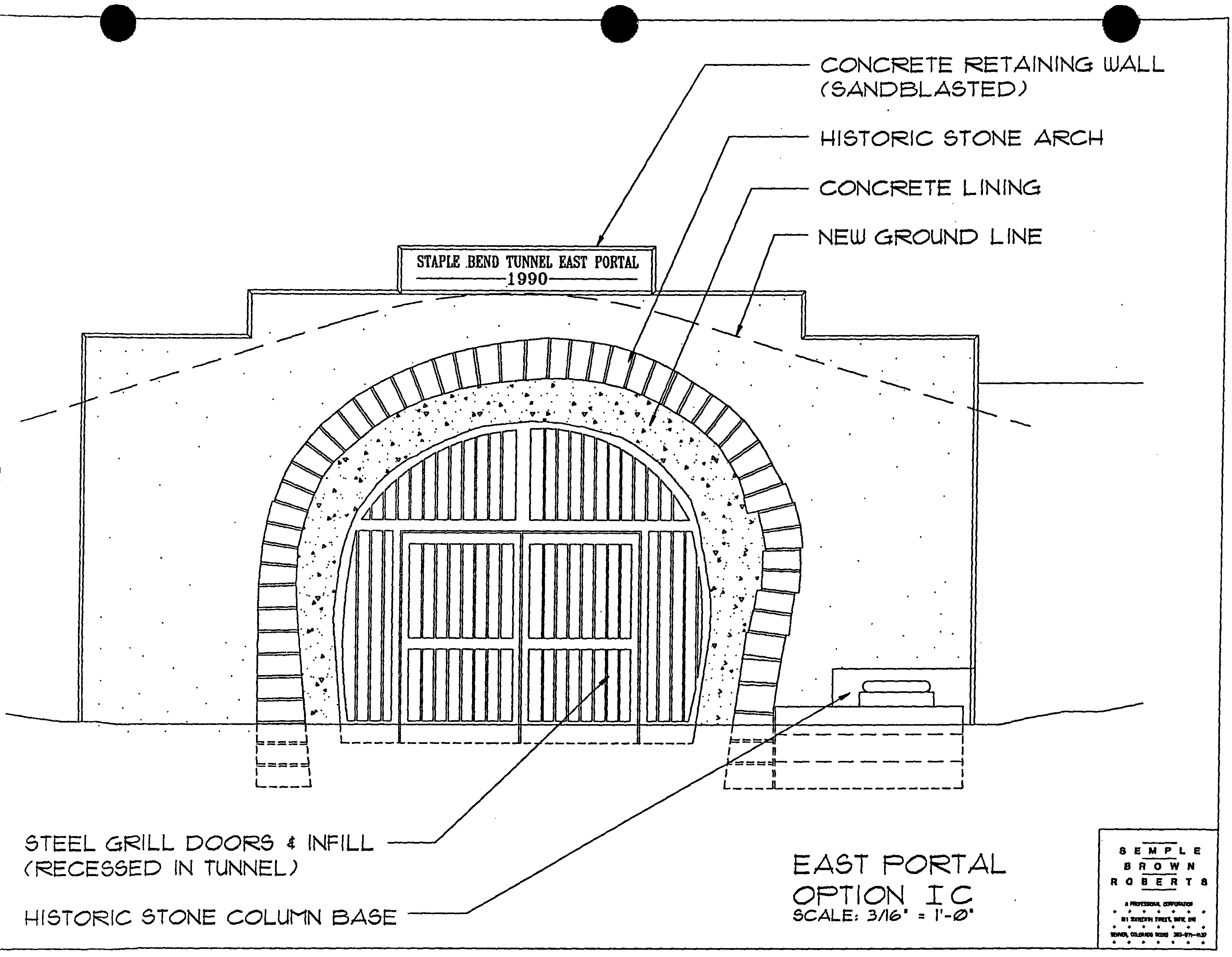


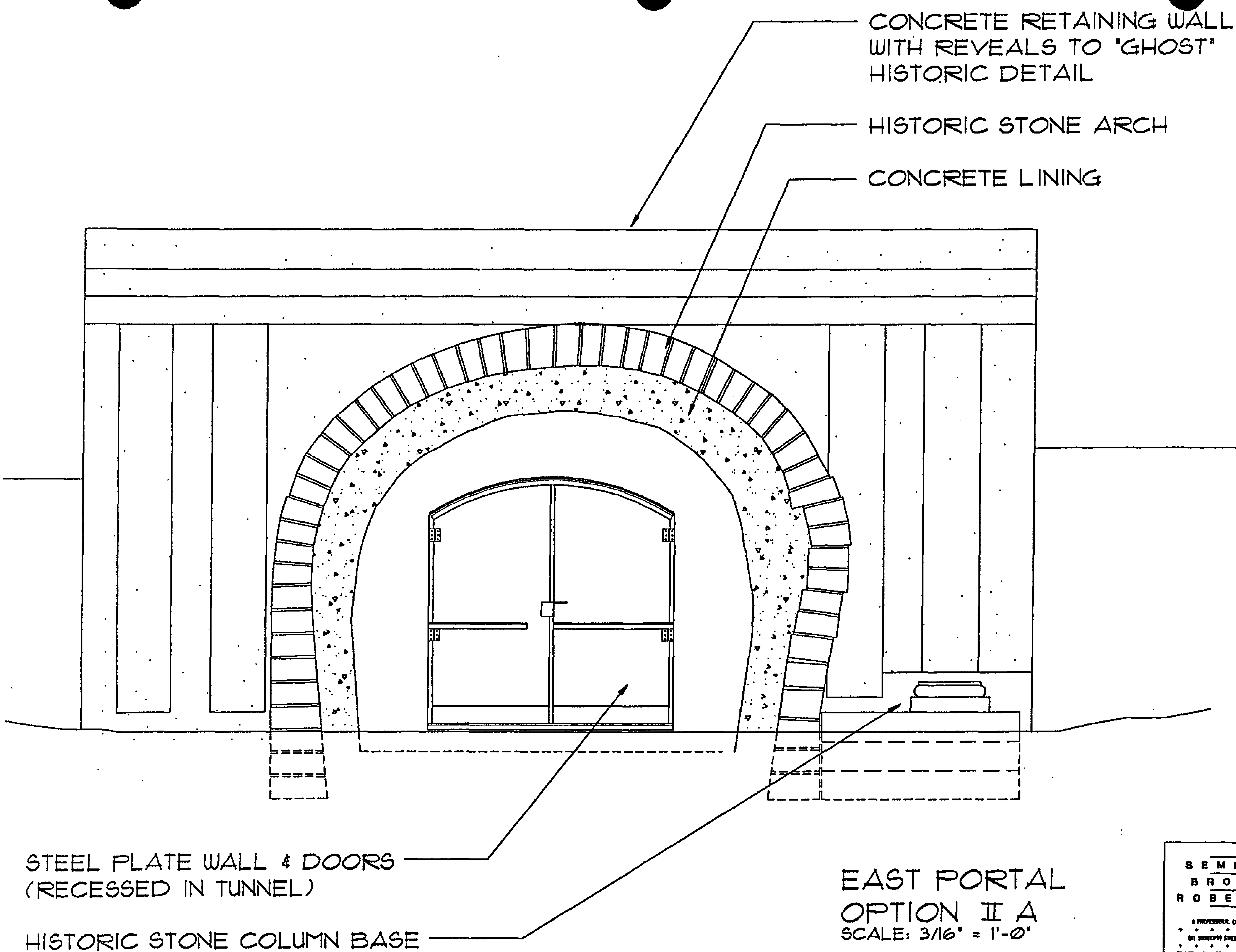
EAST PORTAL OPTIONS
STAPLE BEND TUNNEL


CONCRETE RETAINING WALL
(SANDBLASTED)
HISTORIC STONE ARCH
CONCRETE LINING
NEW GROUND LINE
STAPLE BEND TUNNEL EAST PORTAL
1990
STEEL PLATE WALLS & DOORS
(RECESSED IN TUNNEL)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION I A
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION



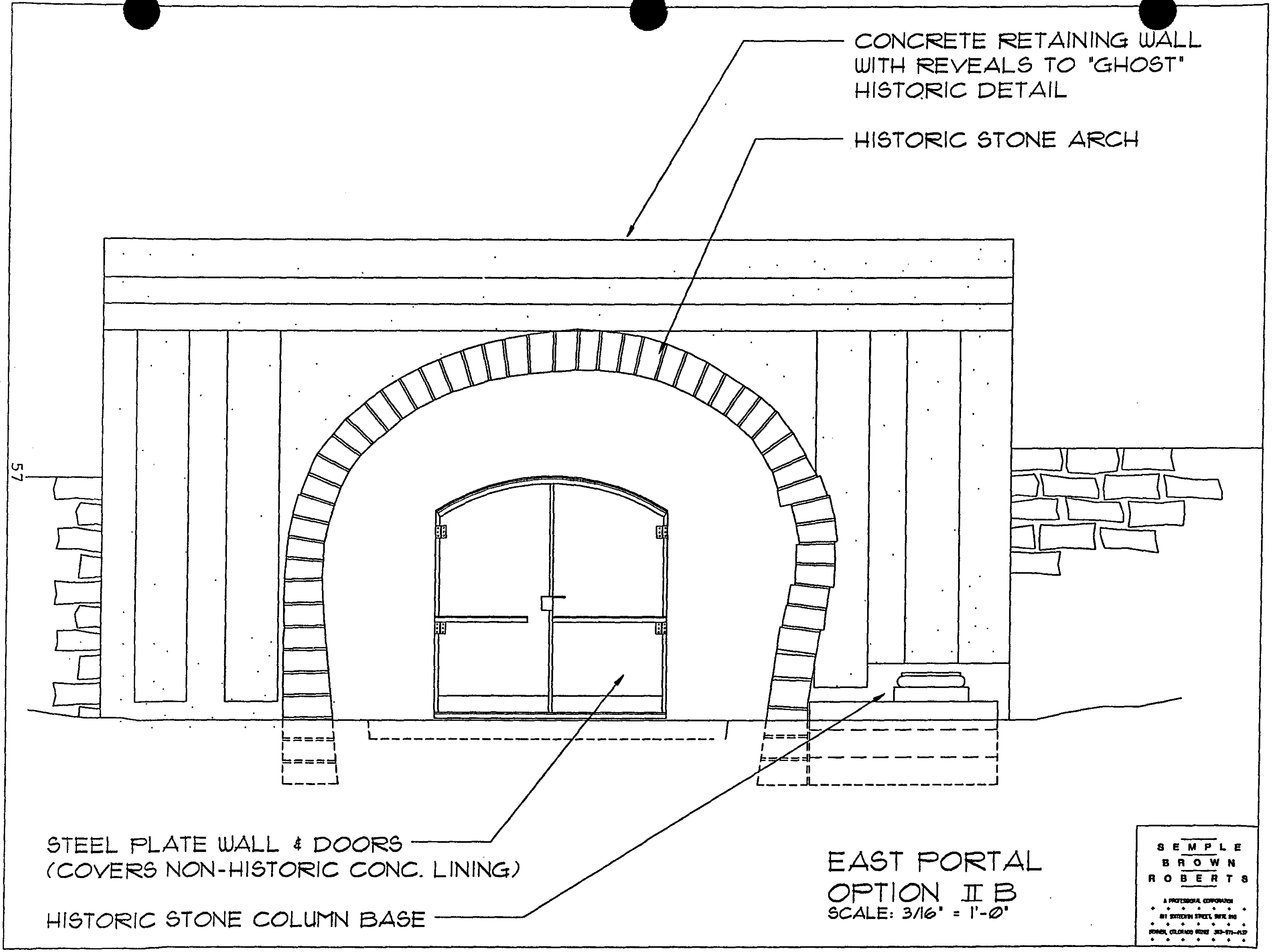
EAST PORTAL
OPTION IB
SCALE: 3/16" = 1'-0"


CONCRETE RETAINING WALL
(SANDBLASTED)
HISTORIC STONE ARCH
CONCRETE LINING
NEW GROUND LINE
STAPLE BEND TUNNEL EAST PORTAL
1990
STEEL GRILL DOORS & INFILL
(RECESSED IN TUNNEL)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION IC
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION

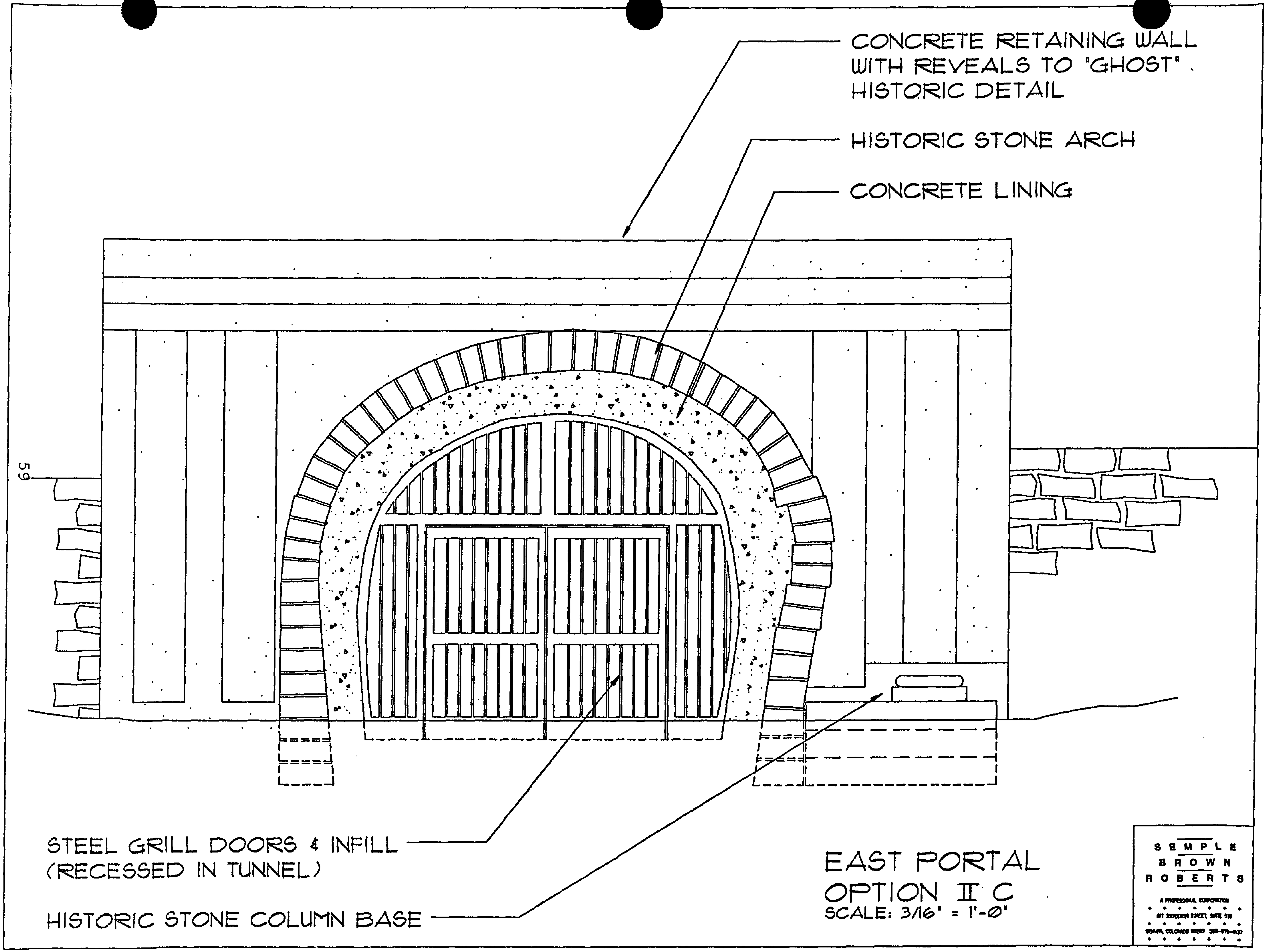


EAST PORTAL
OPTION II A
SCALE: 3/16" = 1'-0"

SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION


CONCRETE RETAINING WALL
WITH REVEALS TO "GHOST"
HISTORIC DETAIL
HISTORIC STONE ARCH
STEEL PLATE WALL & DOORS
(COVERS NON-HISTORIC CONC. LINING)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION II B
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION

57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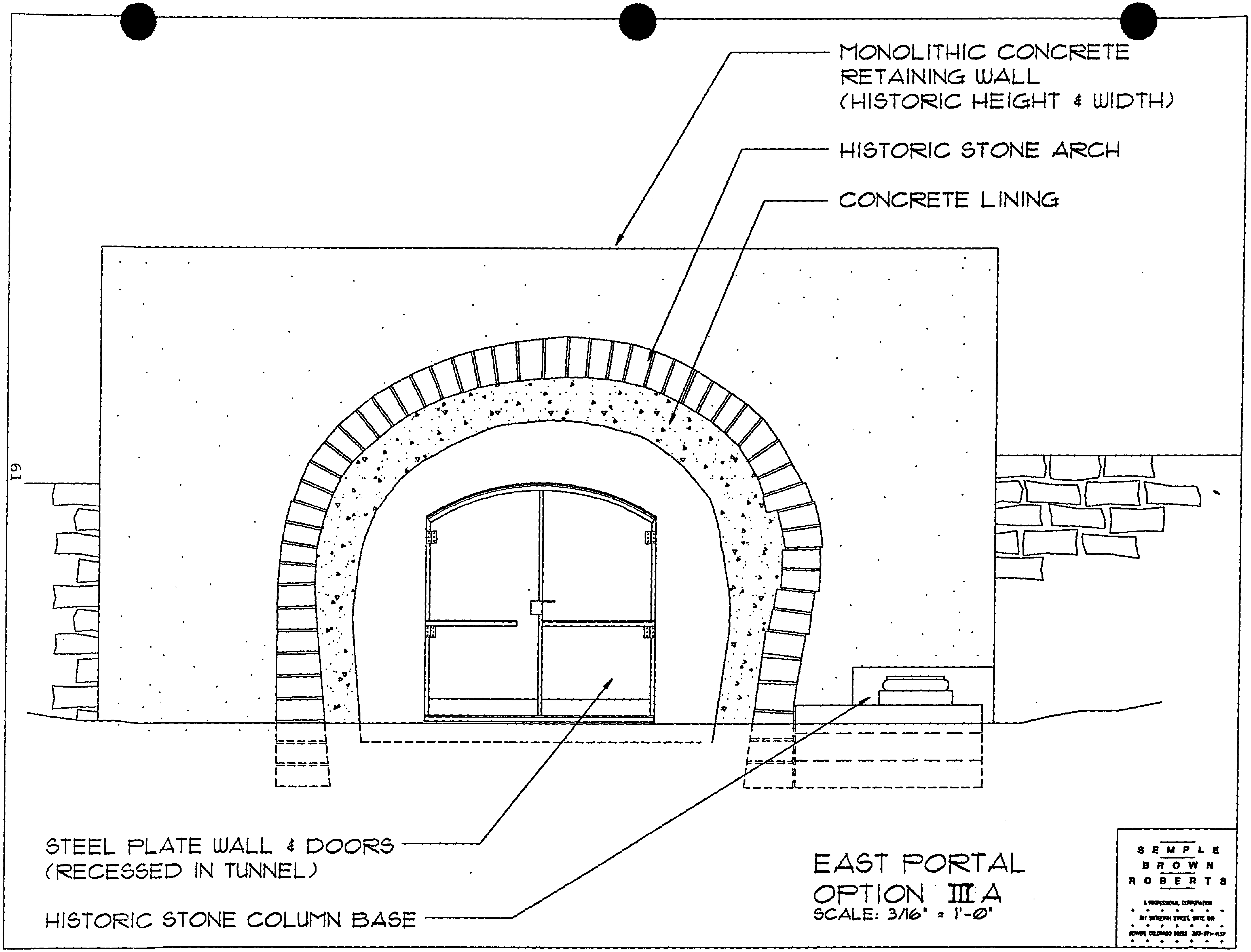
HISTORIC STONE ARCH
CONCRETE LINING
STEEL GRILL DOORS & INFILL (RECESSED IN TUNNEL)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION II C
SCALE: 3/16" = 1'-0"
SEMPLE BROWN ROBERTS
A PROFESSIONAL CORPORATION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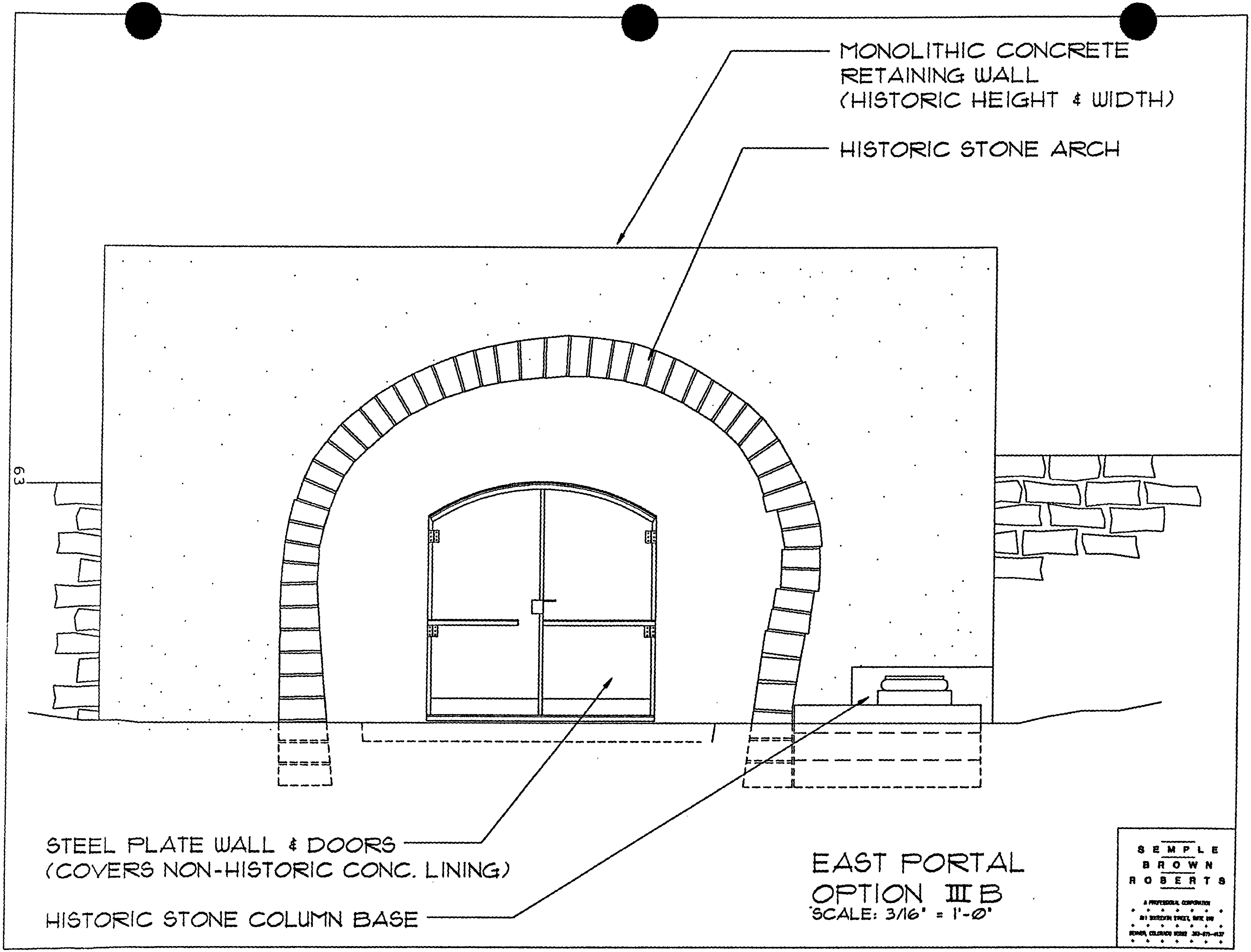
RETAINING WALL
(HISTORIC HEIGHT & WIDTH)
HISTORIC STONE ARCH
CONCRETE LINING
STEEL PLATE WALL & DOORS
(RECESSED IN TUNNEL)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION III A
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION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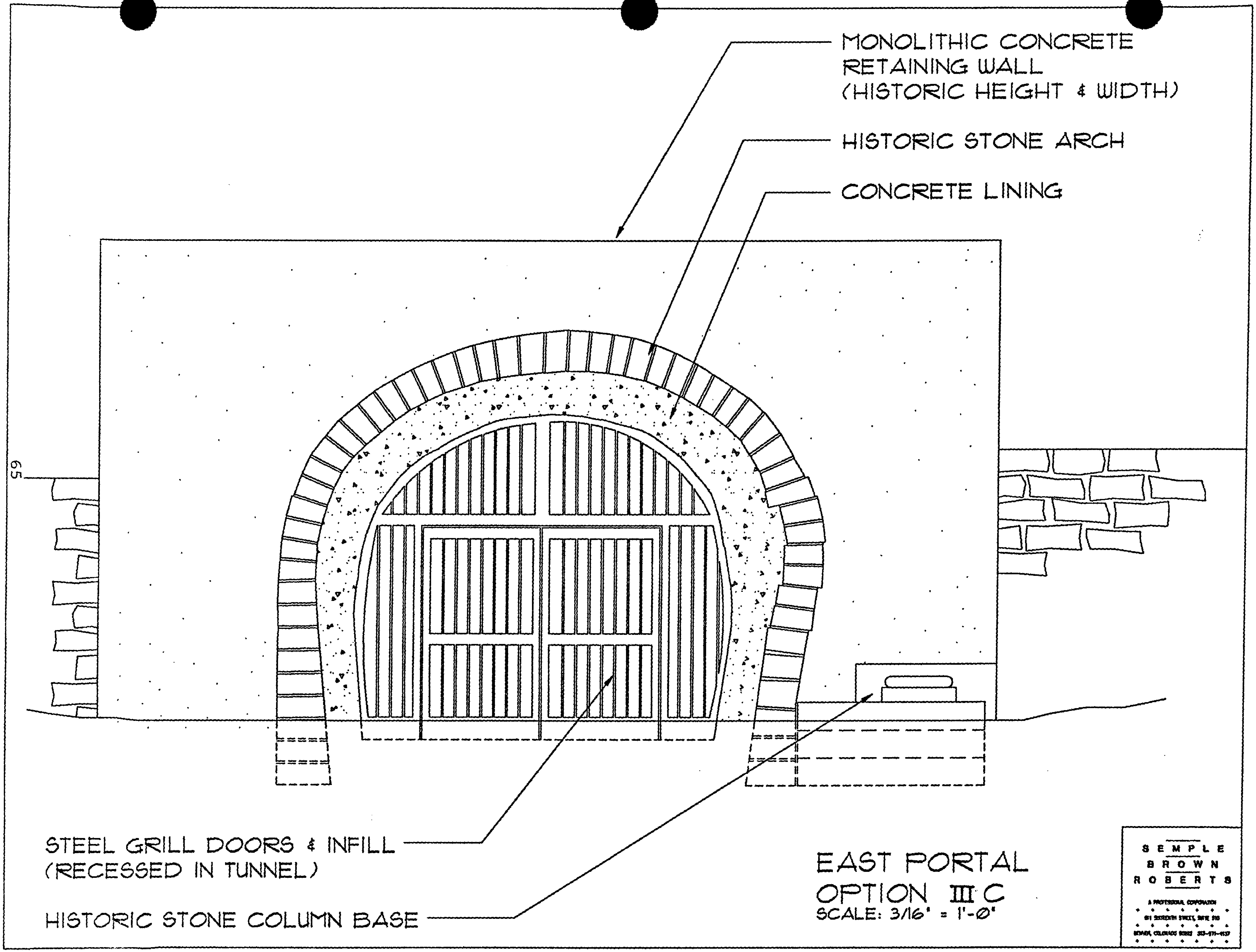
RETAINING WALL
(HISTORIC HEIGHT & WIDTH)
HISTORIC STONE ARCH
STEEL PLATE WALL & DOORS
(COVERS NON-HISTORIC CONC. LINING)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION III B
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS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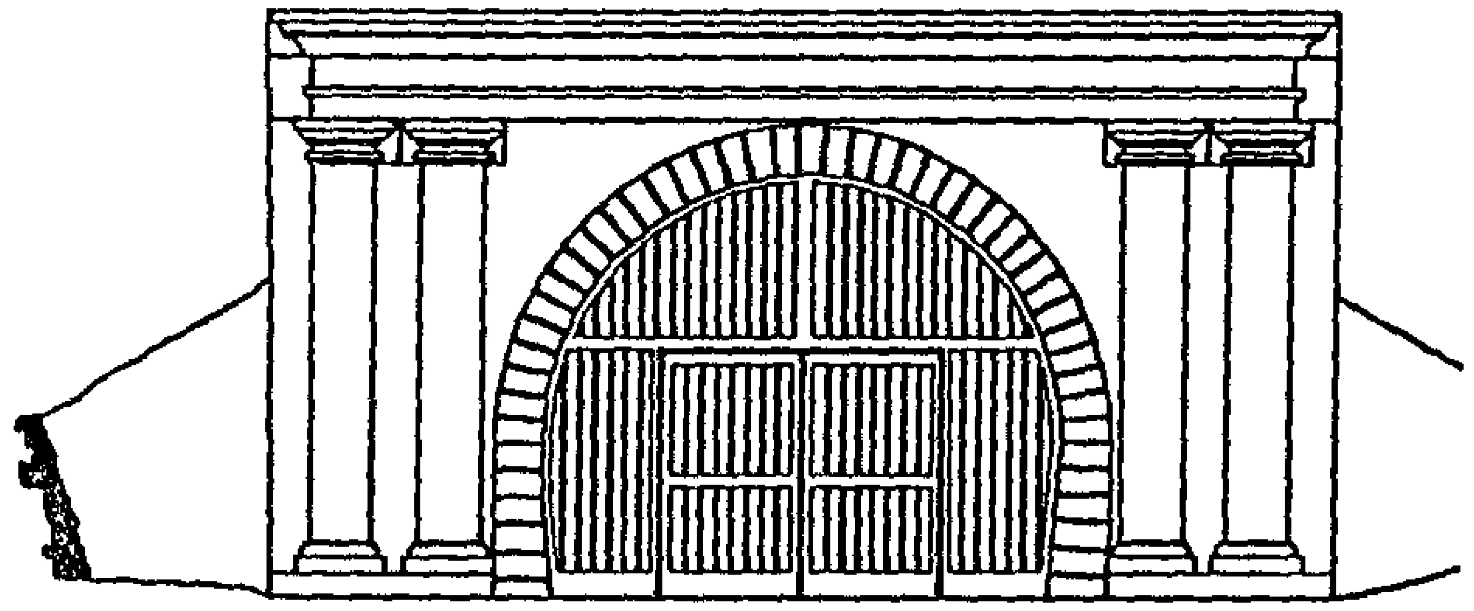
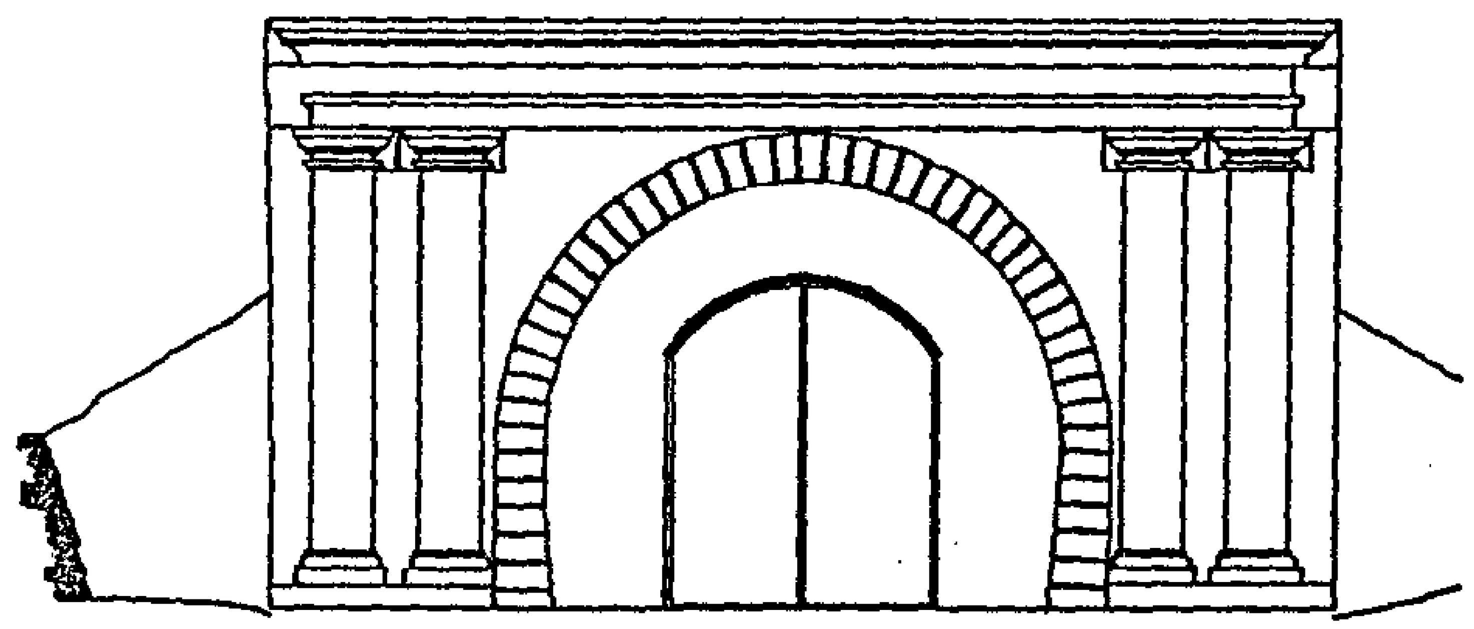
RETAINING WALL
(HISTORIC HEIGHT & WIDTH)
HISTORIC STONE ARCH
CONCRETE LINING
STEEL GRILL DOORS & INFILL
(RECESSED IN TUNNEL)
HISTORIC STONE COLUMN BASE
EAST PORTAL
OPTION III C
SCALE: 3/16" = 1'-0"
SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION



CLOSURE OPTION C



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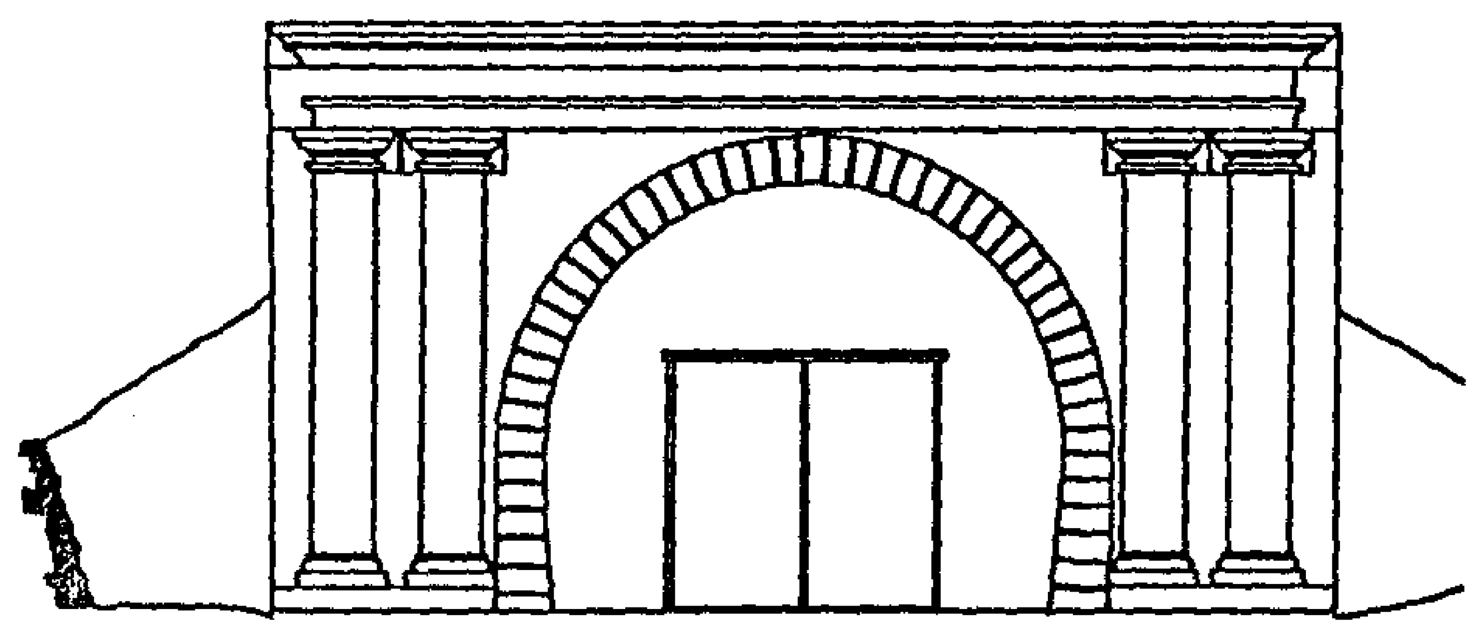
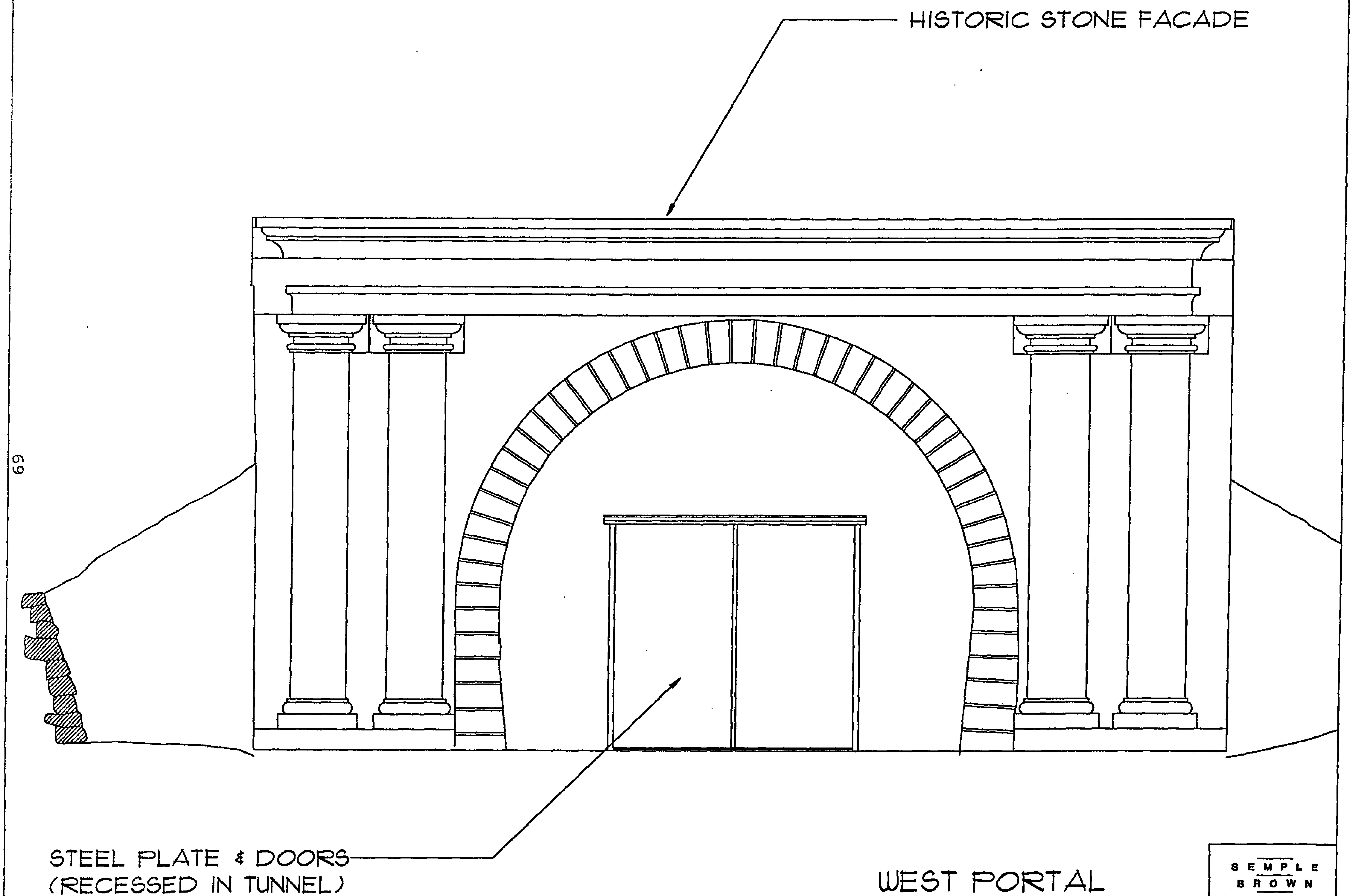


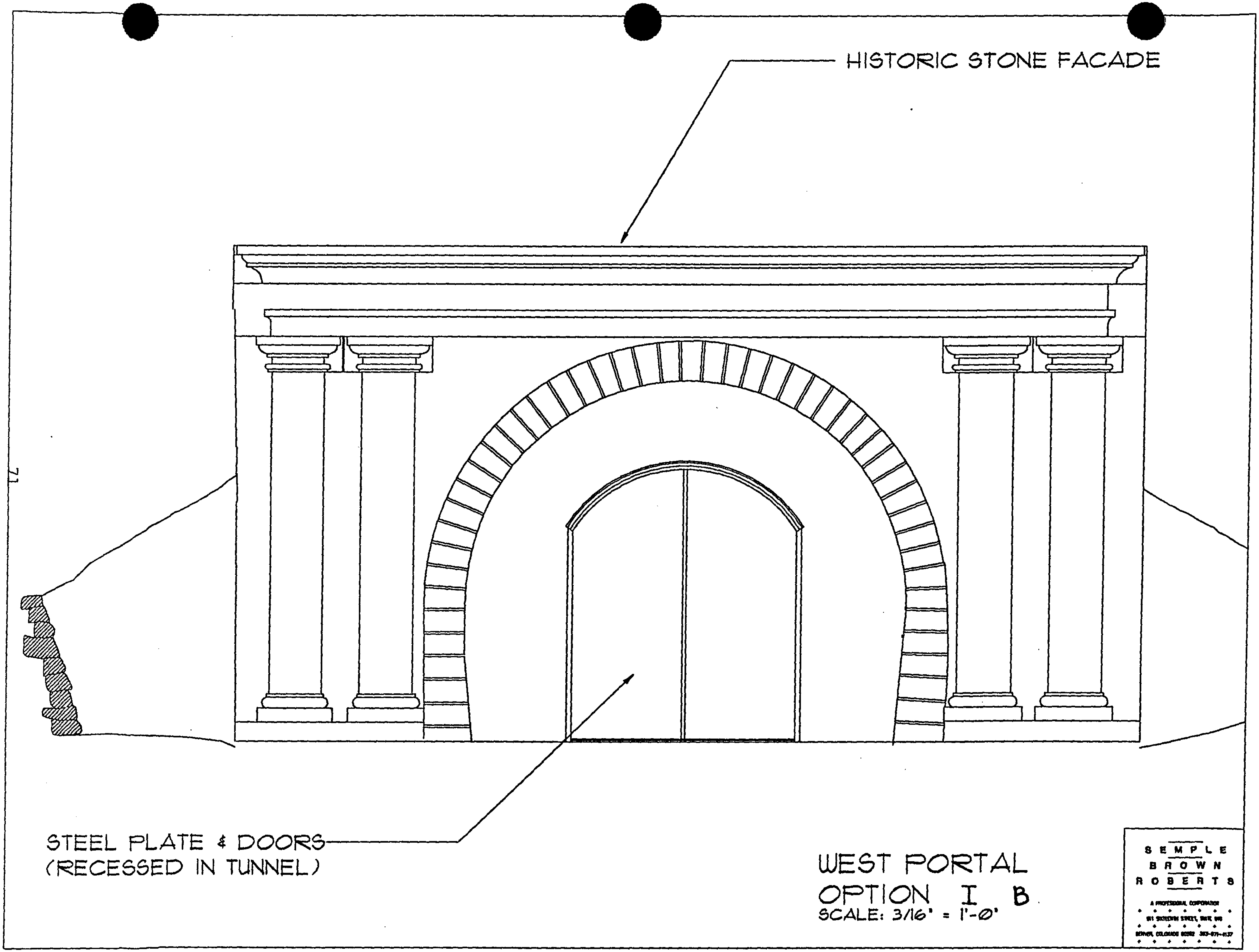
CLOSURE OPTION A

ELEVATION I
WEST PORTAL OPTIONS
STAPLE BEND TUNNEL

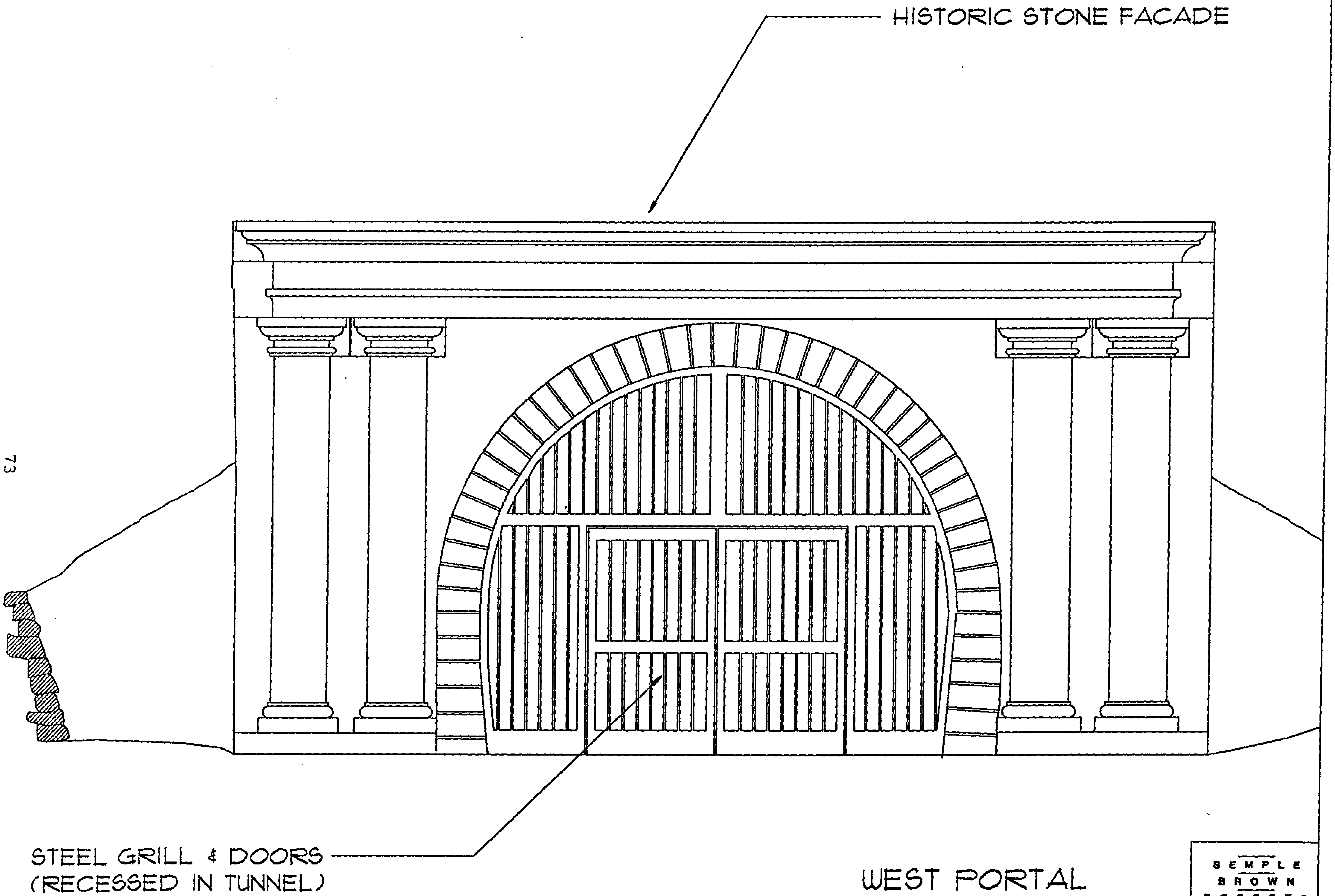


WEST PORTAL
OPTION I A
SCALE: 3/16" = 1'-0"

SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION

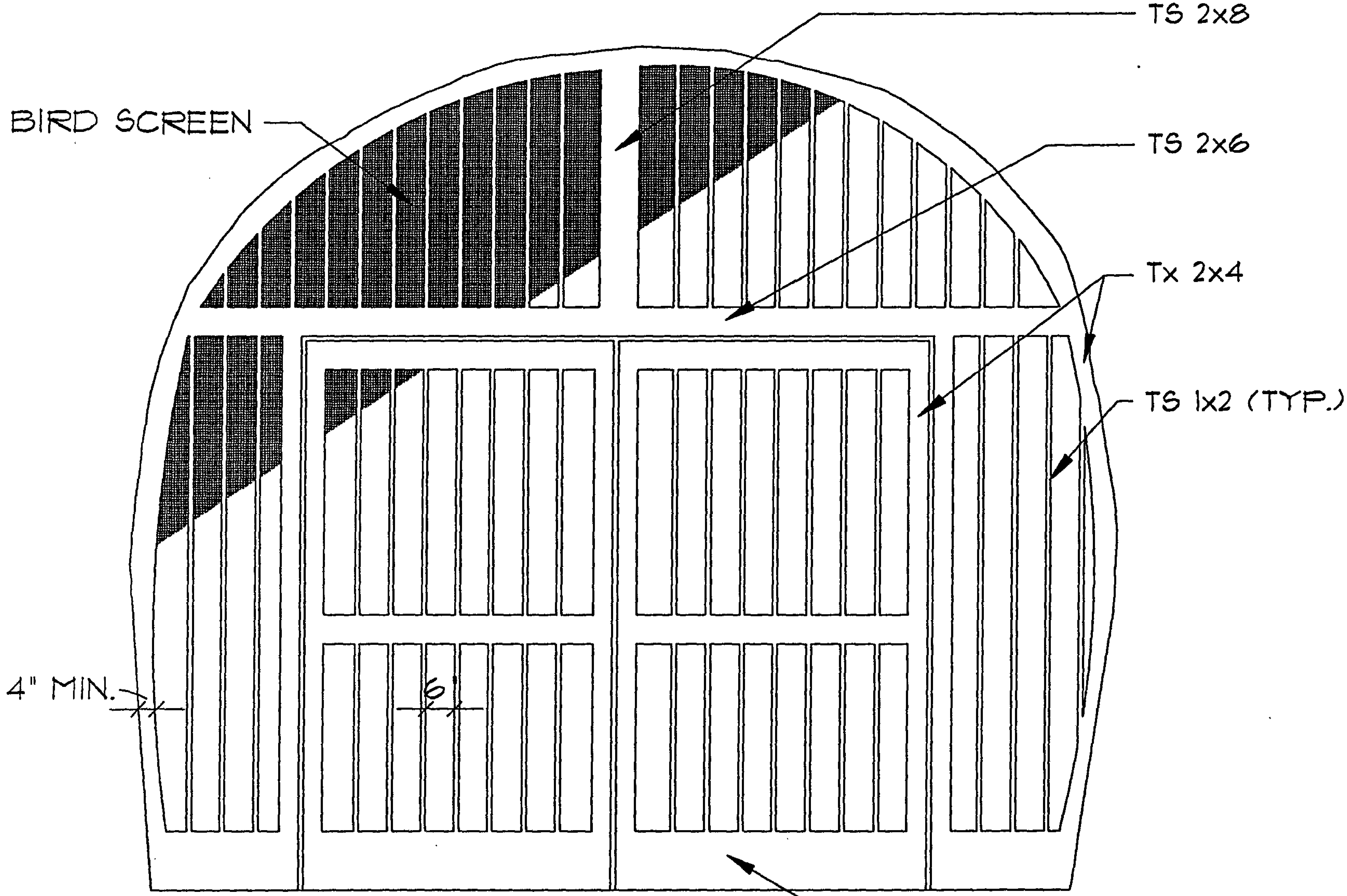


WEST PORTAL
OPTION I B
SCALE: 3/16" = 1'-0"



WEST PORTAL
OPTION I C
SCALE: 3/16" = 1'-0"

SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION

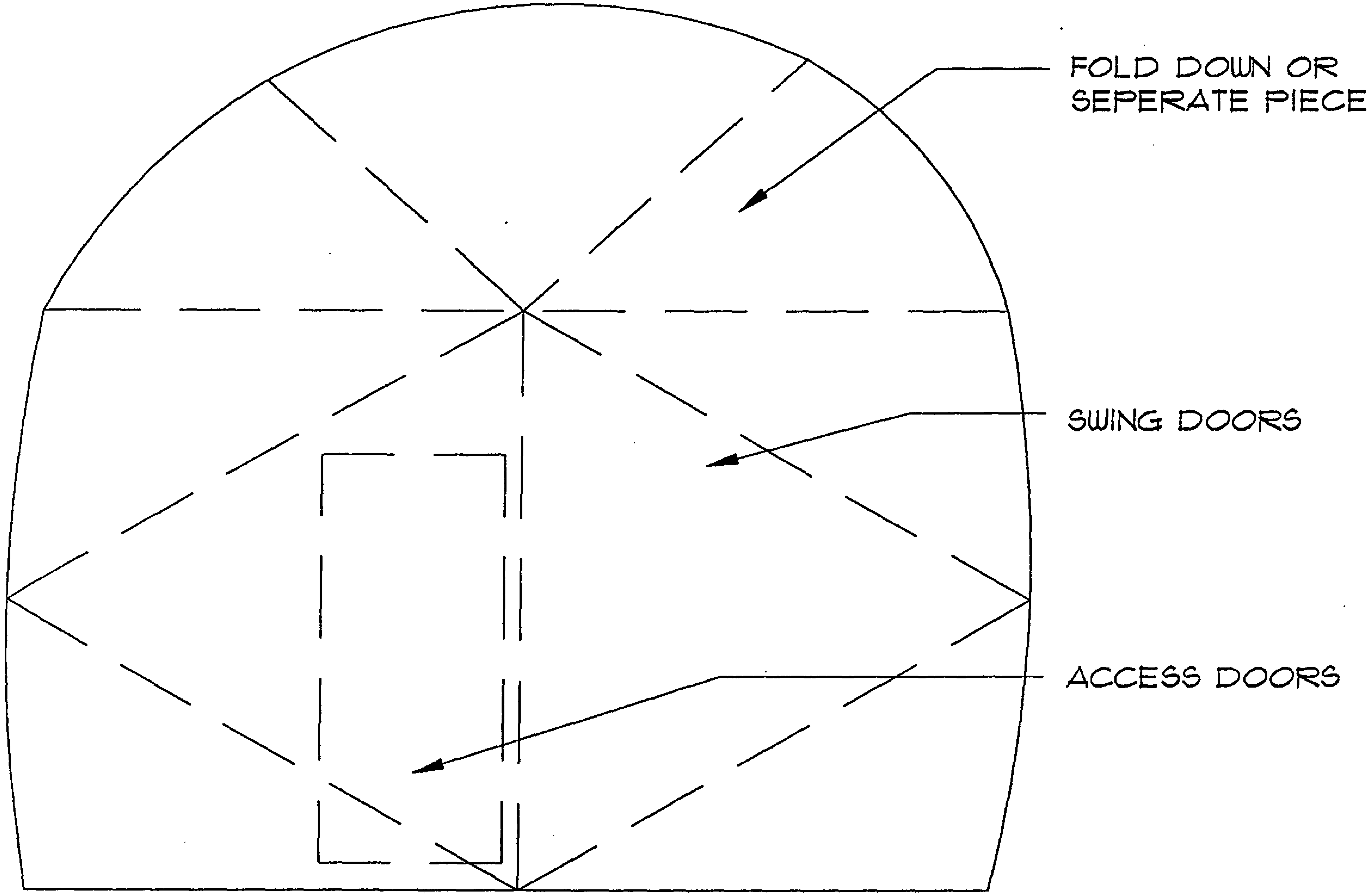


STEEL GRILL INFILL ELEVATION

SCALE: 3/8" = 1'-0"

SEMPLE
BROWN
ROBERTS

A PROFESSIONAL CORPORATION



INFILL OPTION 1

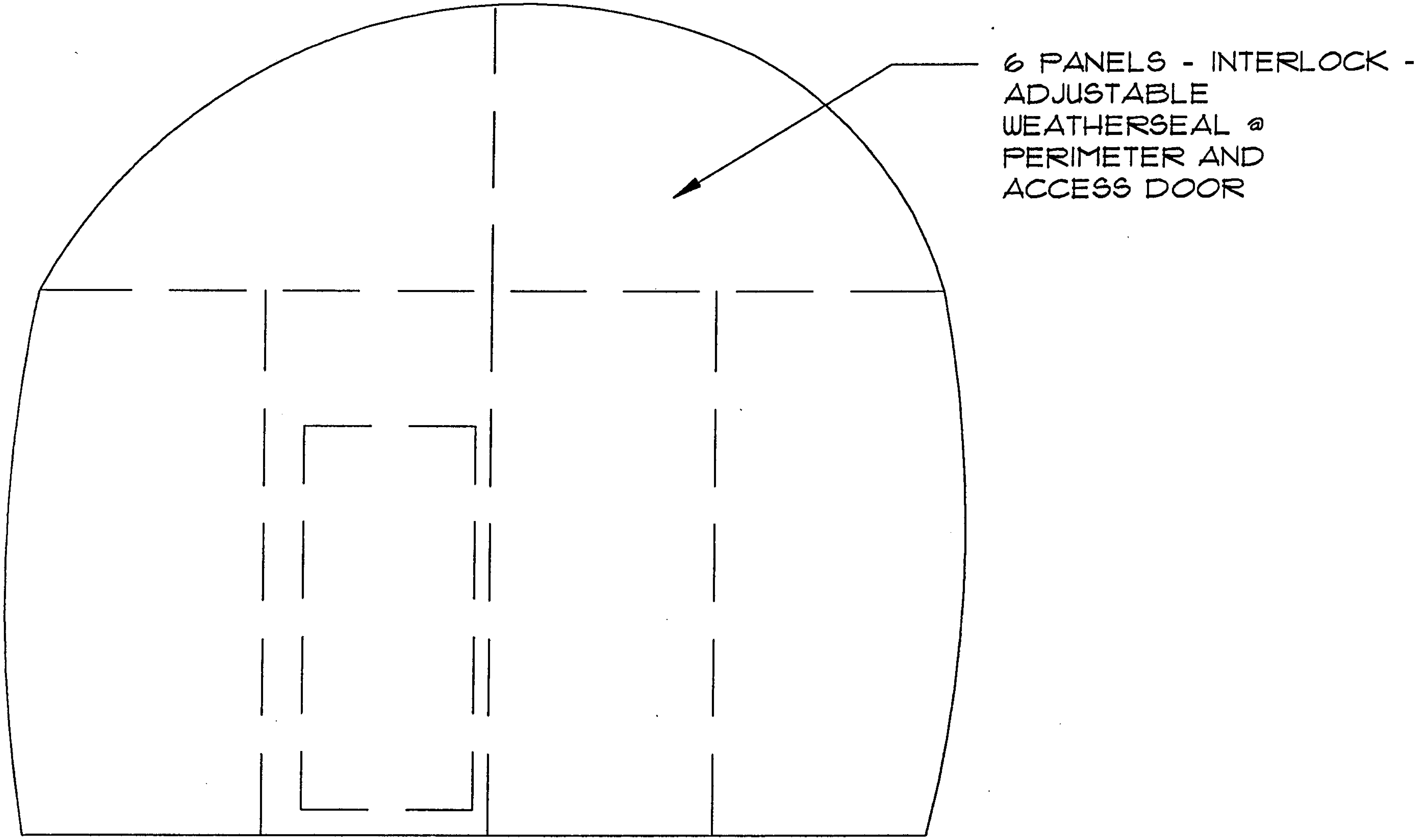
3-PIECE INSULATED INFILL

SCALE: 3/8" = 1'-Ø"

INFILL OPTIONS

1. 1/4" STEEL PLATE
2. ALUMINUM SHEATHED PANELS WITH RIGID INSULATION
3. PAINTED PLYWOOD PANELS

SEMPLE
BROWN
ROBERTS
A PROFESSIONAL CORPORATION

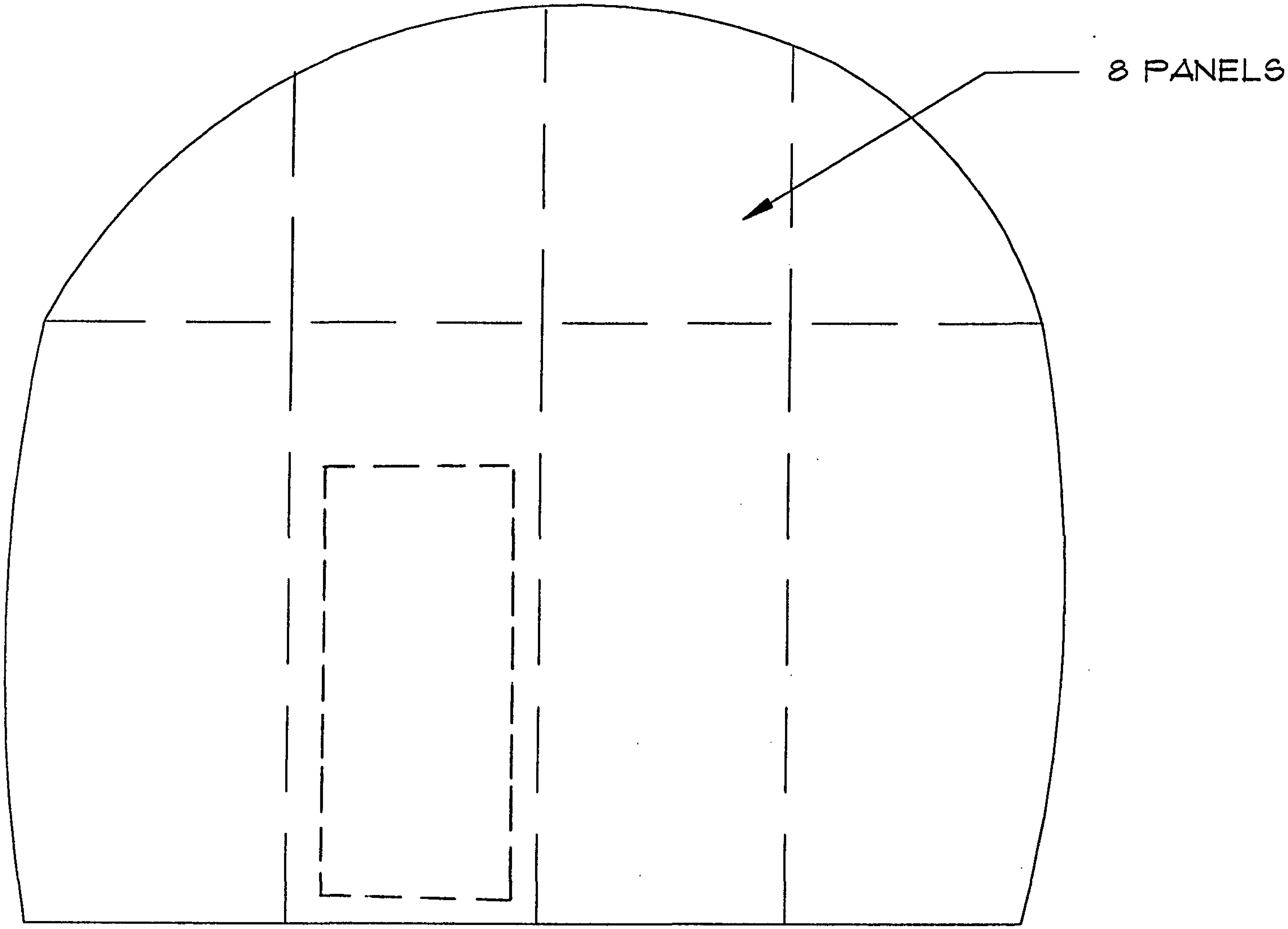


INFILL OPTIONS 2 & 3

EAST (INSUL. INFILL) REMOVEBLE PANELS

SCALE: 3/8" = 1'-Ø"

S E M P L E
B R O W N
R O B E R T S
A PROFESSIONAL CORPORATION



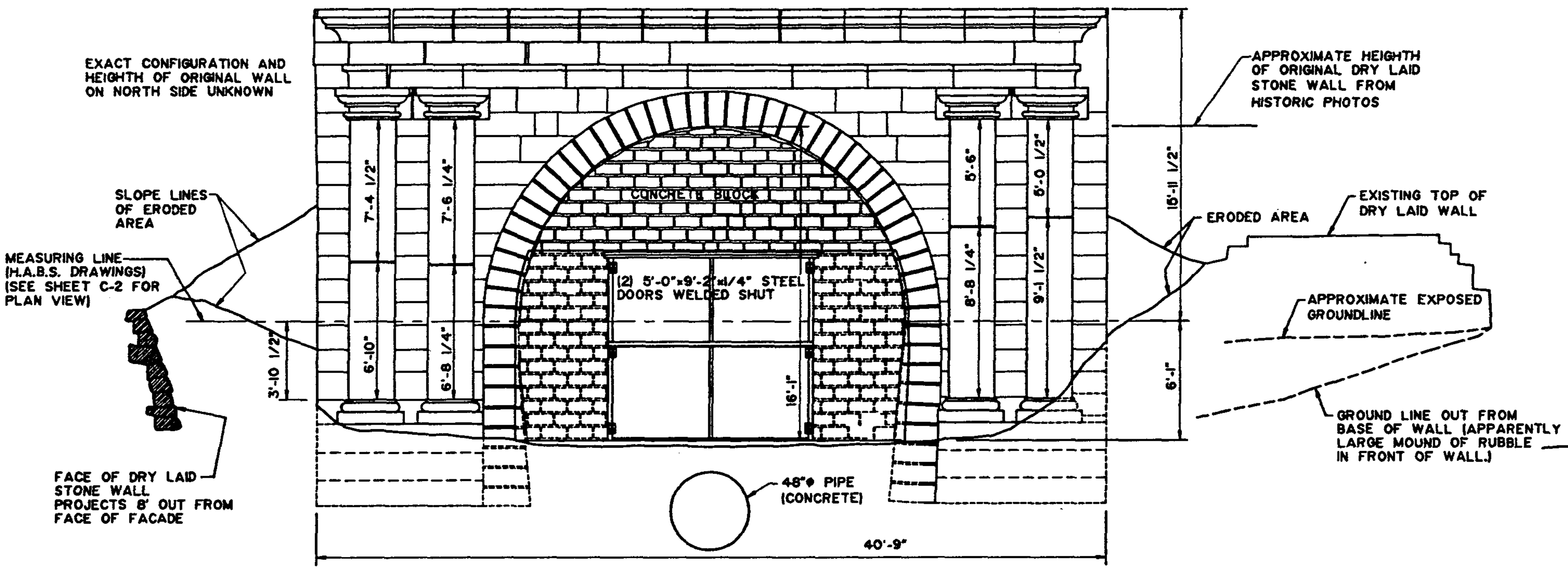
INFILL OPTIONS 2&3

WEST (INSUL. INFILL)

SCALE: 3/8" = 1'-Ø"

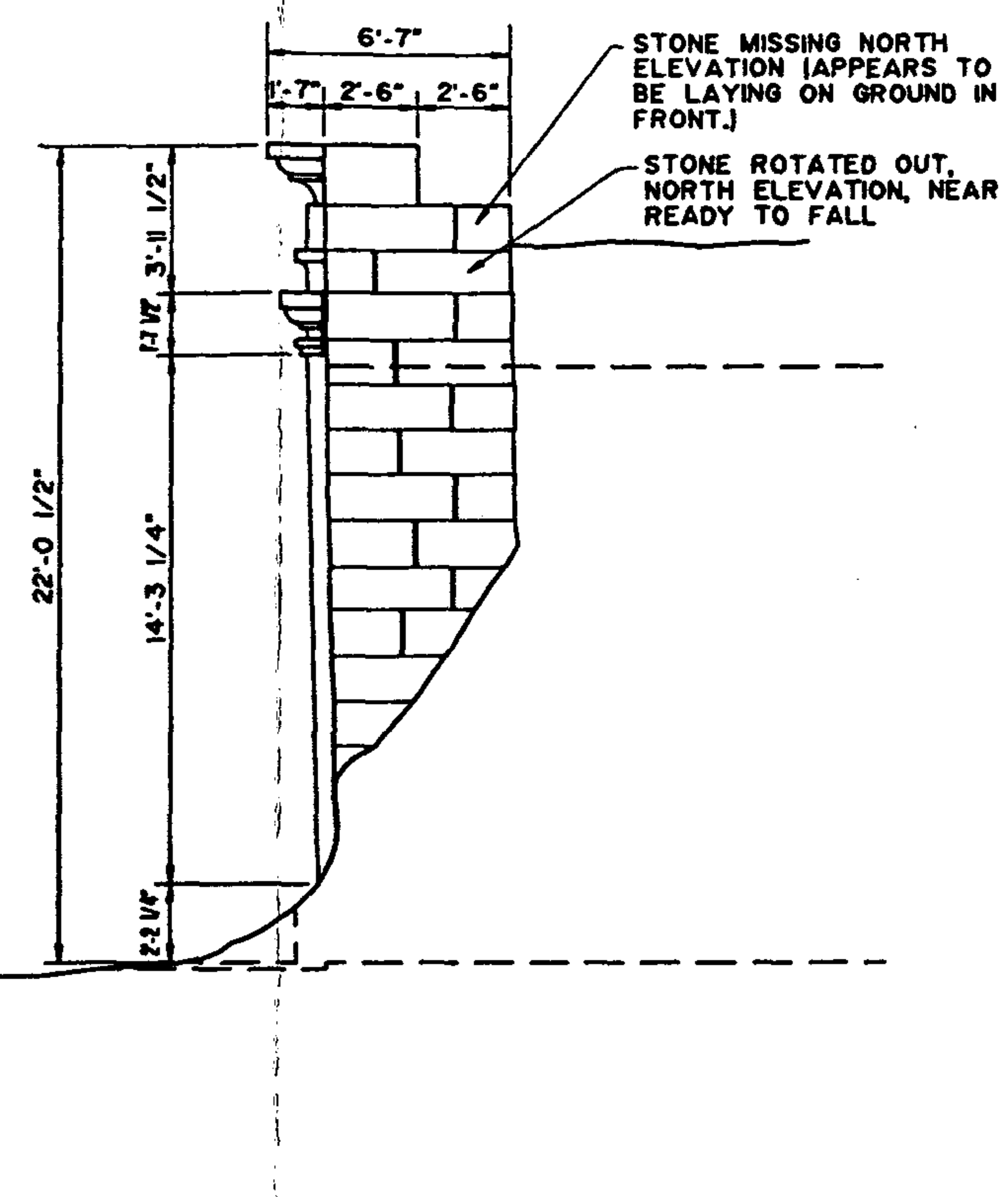
SEMPLE
BROWN
ROBERTS

A PROFESSIONAL CORPORATION



ELEVATION AT WEST PORTAL-EXISTING CONDITIONS

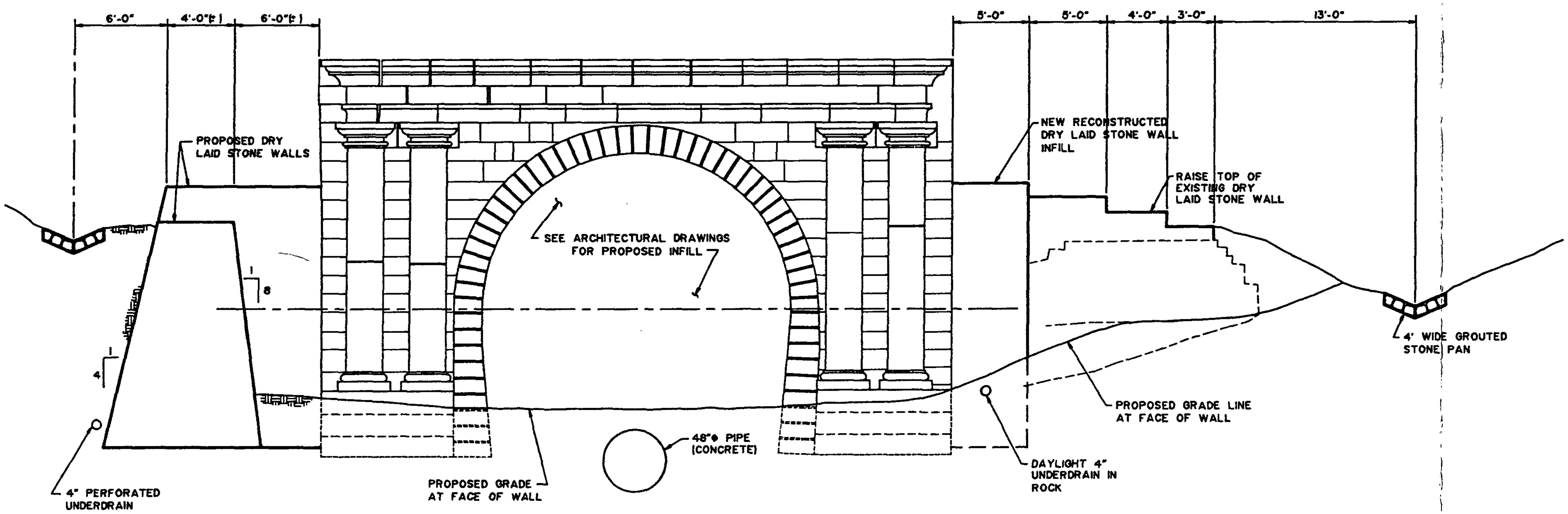
SCALE (A)



NORTH ELEVATION (SIM.)

SOUTH ELEVATION

SCALE (A)



ELEVATION AT WEST PORTAL-PROPOSED IMPROVEMENTS

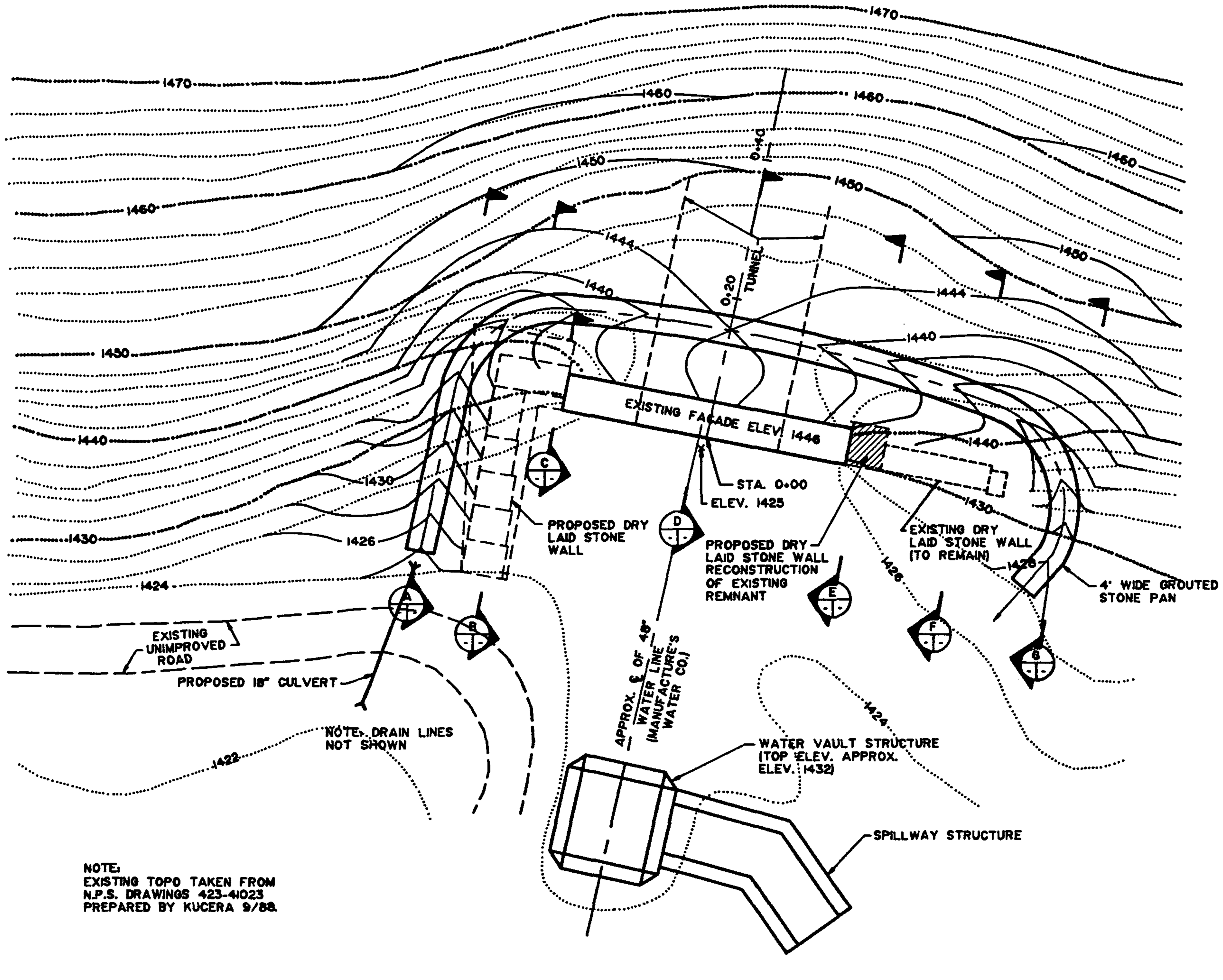
SCALE (A)

ON MICROFILM

SCALE (A) 4 0 4 8

SCALE OF FEET

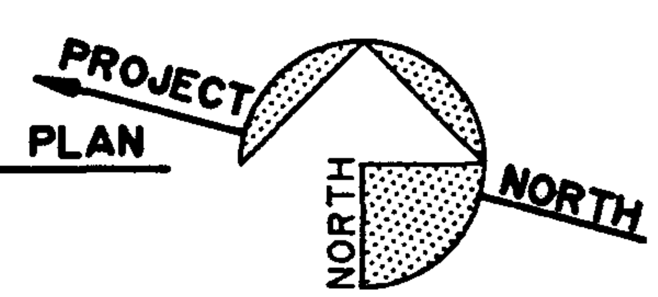
DESIGNED: TAY	SUB SHEET NO.	TITLE OF SHEET	DRAWING NO. 423 25008
DRAWN: DTB	C-1	WEST PORTAL ELEVATIONS	PKG. NO.
TECH. REVIEW:		LOCATION STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	SHEET 1 OF 7
DATE: 3/91			

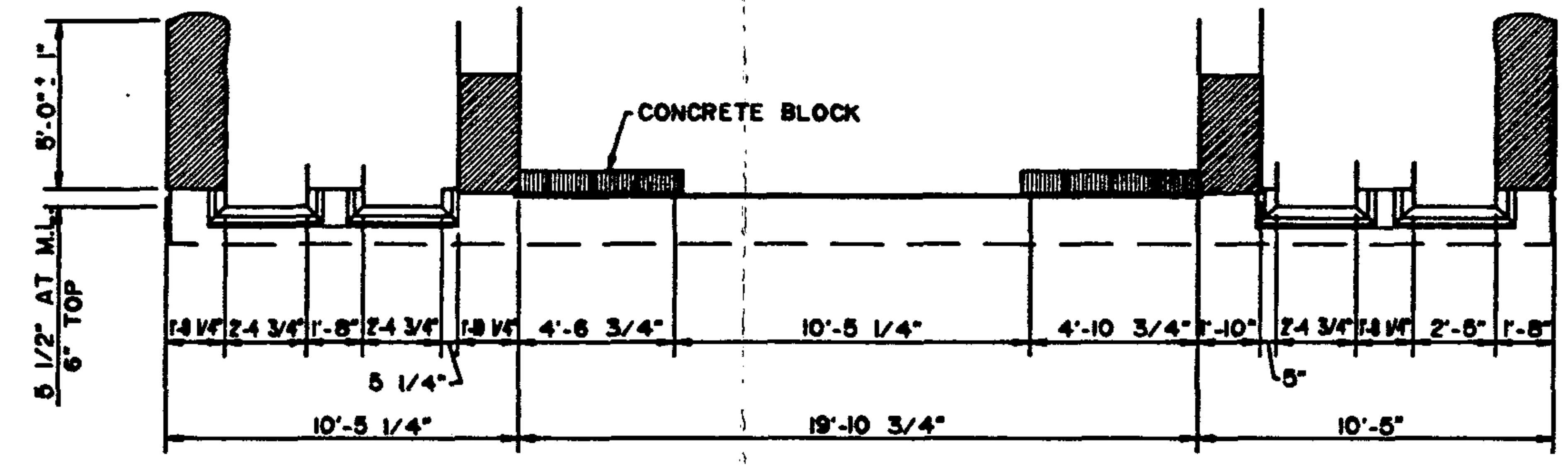


NOTE:
EXISTING TOPO TAKEN FROM N.P.S. DRAWINGS 423-41023 PREPARED BY KUCERA 9/88.

WEST PORTAL-SITE PLAN

SCALE Ⓐ





PLAN AT MEASURING LINE LEVEL (H.A.B.S. DRAWING)

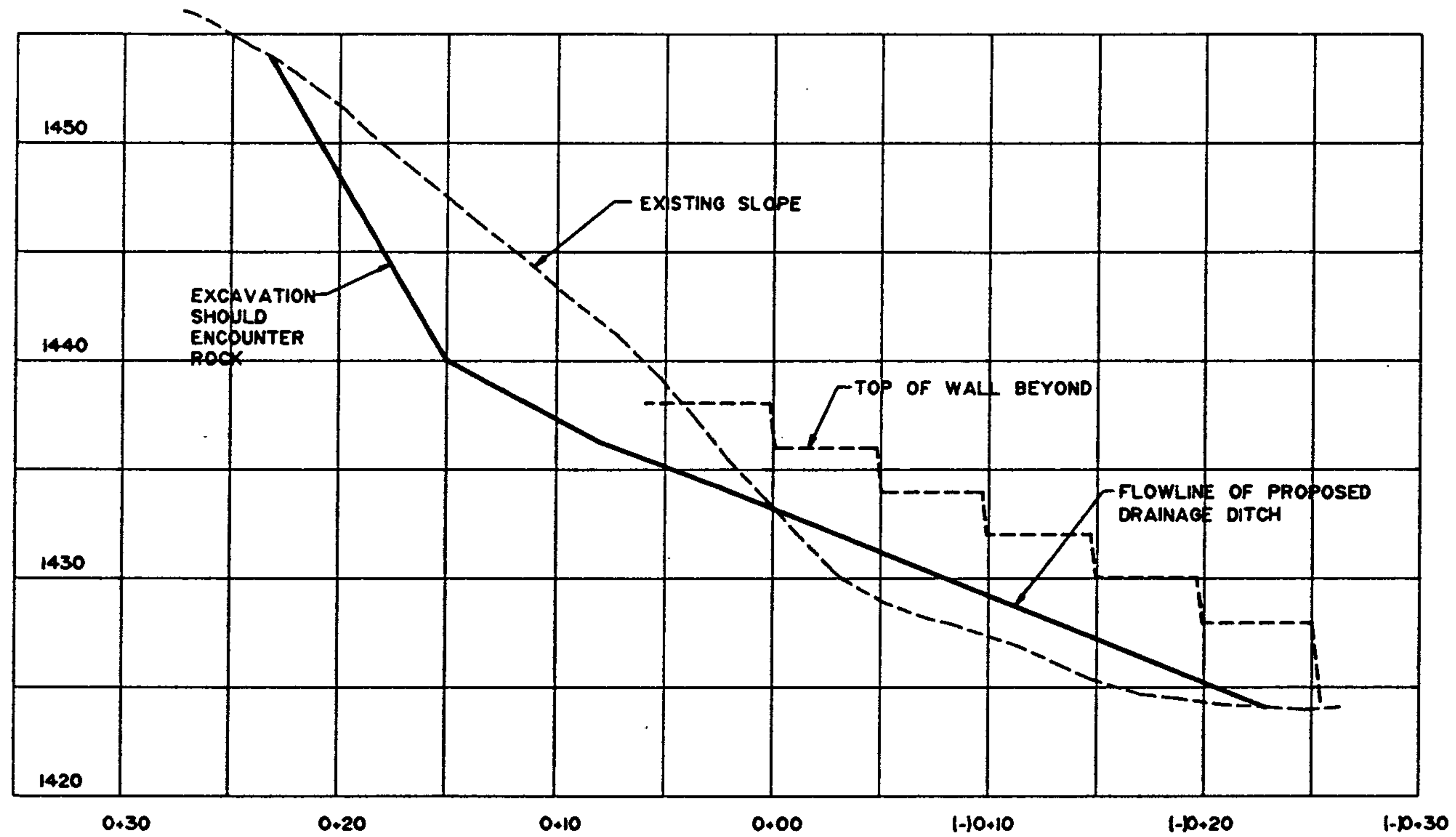
SCALE Ⓑ

ON MICROFILM

SCALE Ⓑ 4 0 4 8
SCALE OF FEET

SCALE Ⓐ 10 5 0 10 20
SCALE OF FEET

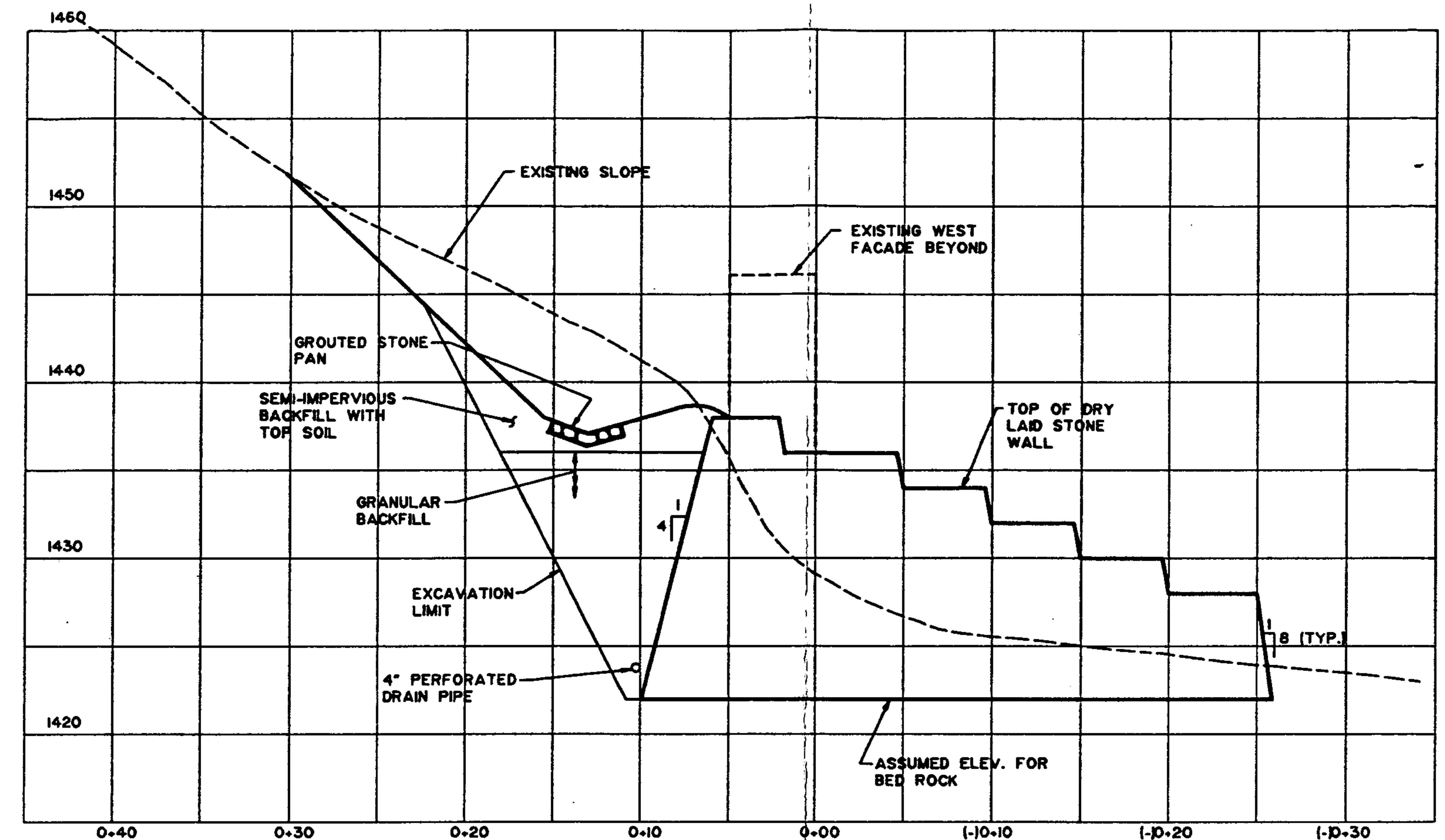
DESIGNED: TAY DRAWN: DTB TECH. REVIEW: DATE: 3/91	SUB SHEET NO. C-2	TITLE OF SHEET WEST PORTAL SITE PLAN LOCATION STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	DRAWING NO. 423 25008 PKG. NO. SHEET 2 OF 7



37' NORTH OF ℄

SECTION (A)

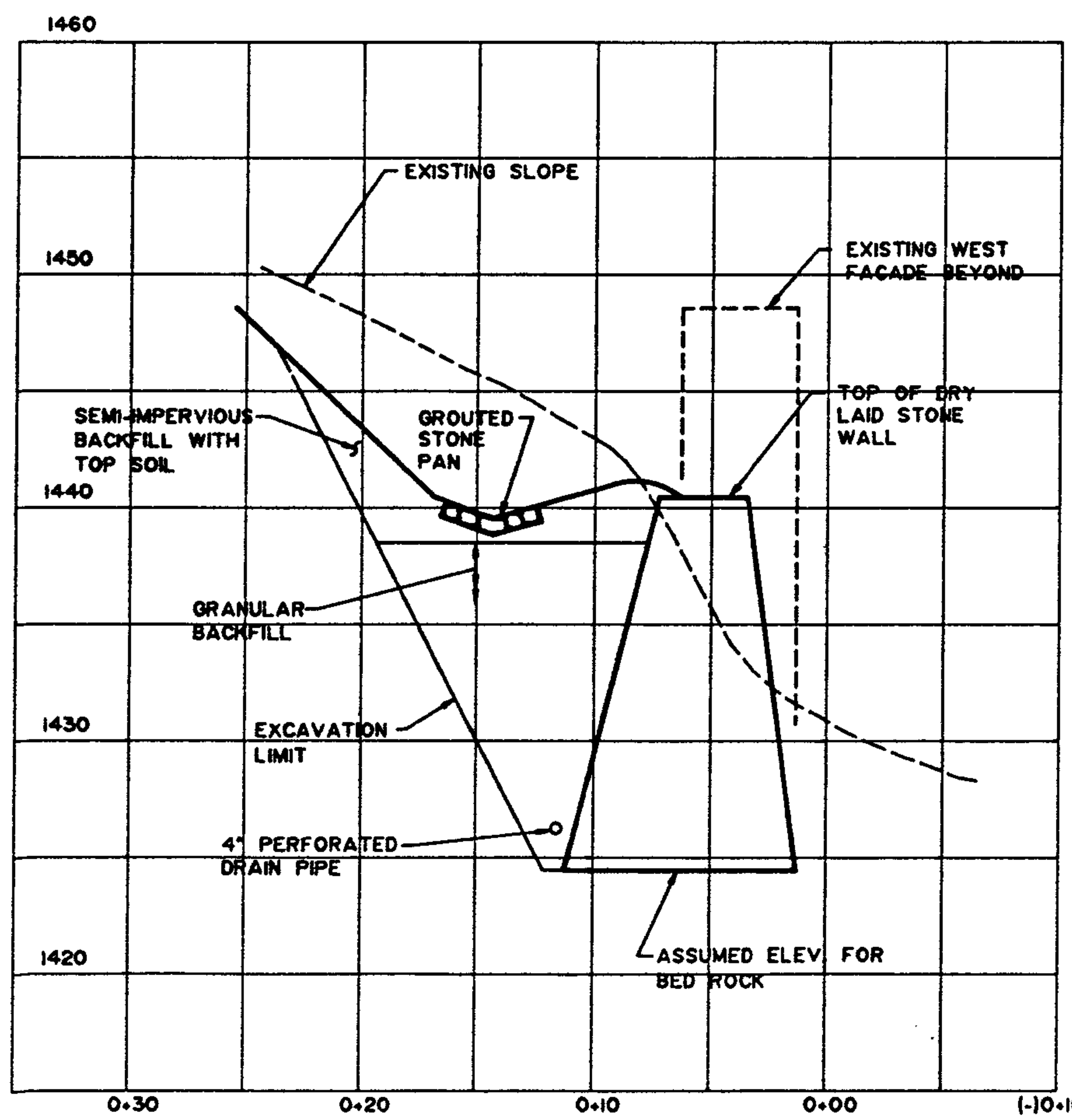
SCALE (A)



27' NORTH OF ℄

SECTION (B)

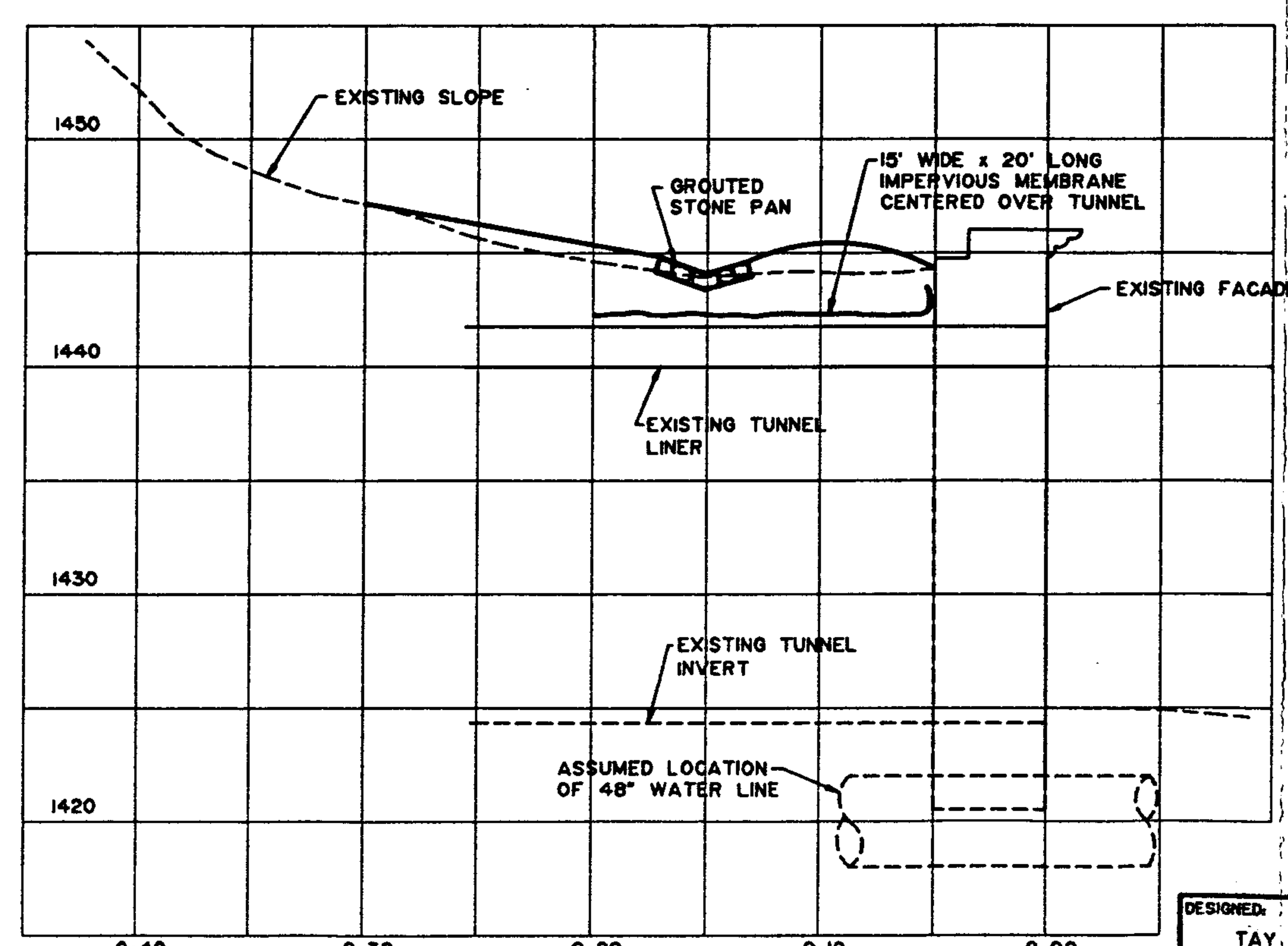
SCALE (A)



22' NORTH OF ℄

SECTION (C)

SCALE (A)



℄ OF TUNNEL

SECTION (D)

SCALE (A)

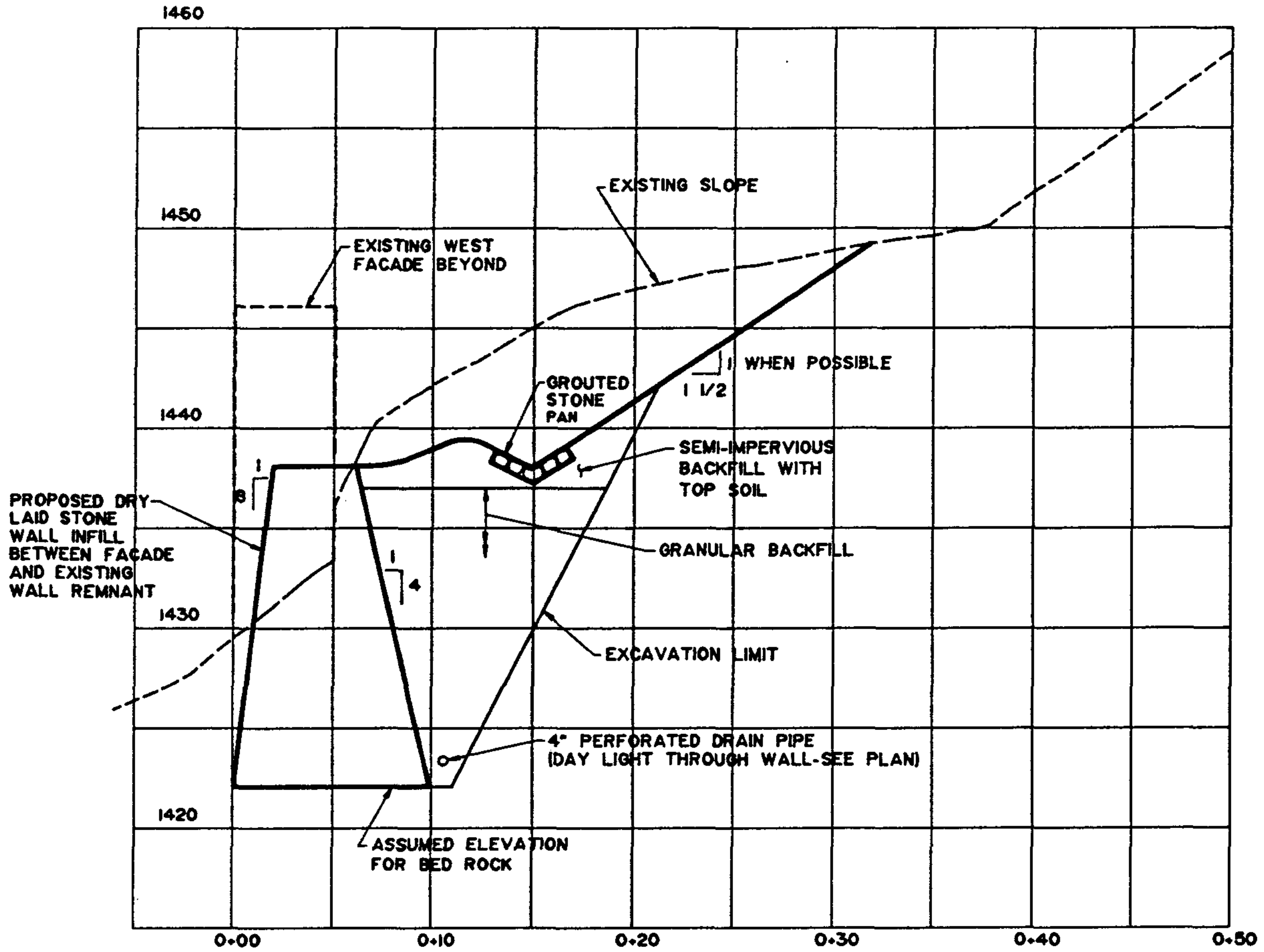
ON MICROFILM

SCALE (A) HORIZ. 5 0 5 10

VERT. 5 0 5 10

SCALE OF FEET

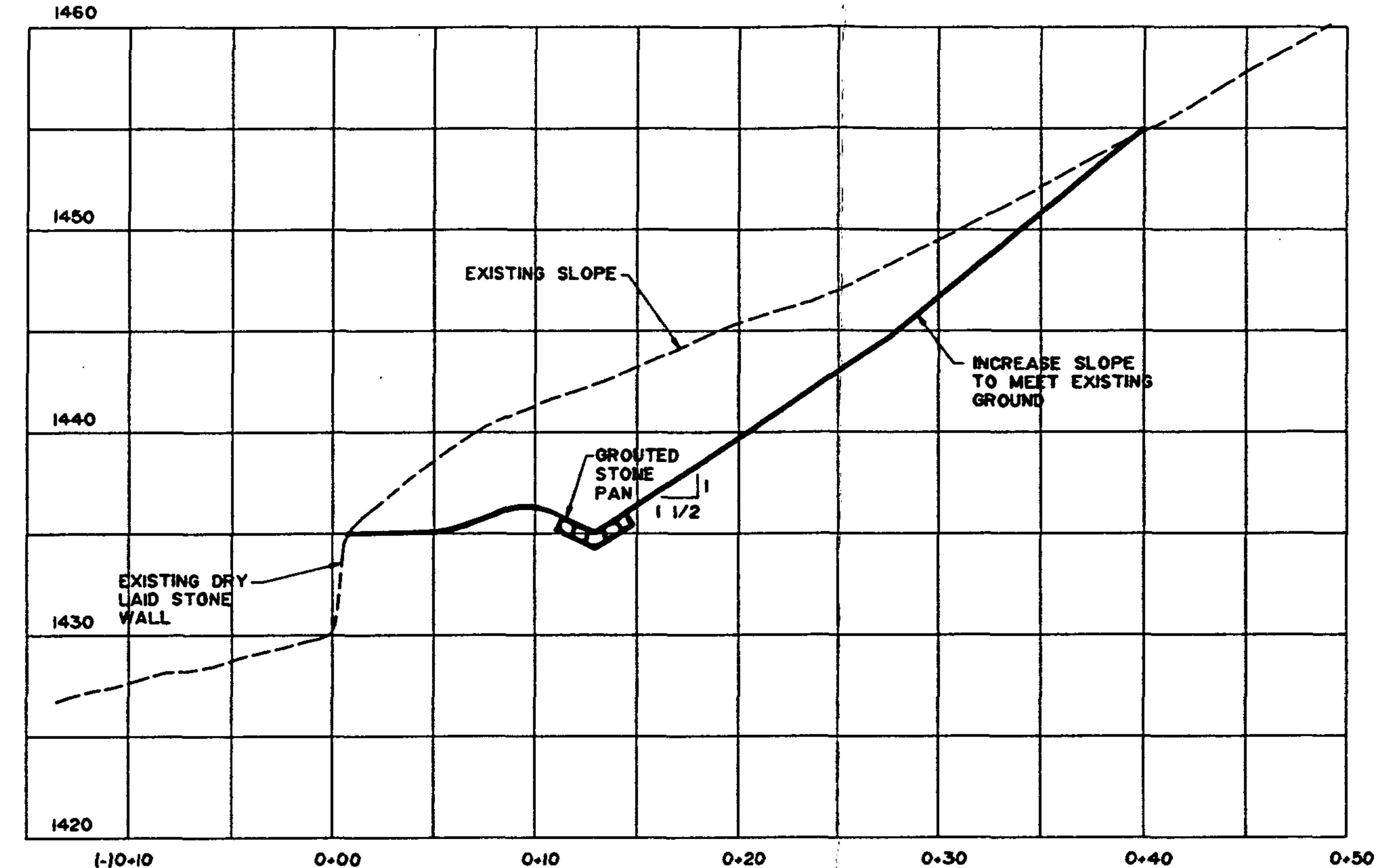
DESIGNED: TAY	SUB SHEET NO.	TITLE OF SHEET	DRAWING NO.
DRAWN: DTB	C-3	**WEST PORTAL CROSS SECTIONS**	423 25008
TECH. REVIEW:		LOCATION	PKG. NO. / SHEET 3
DATE: 3/91		STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	OF 7



22' SOUTH OF ℄

SECTION E

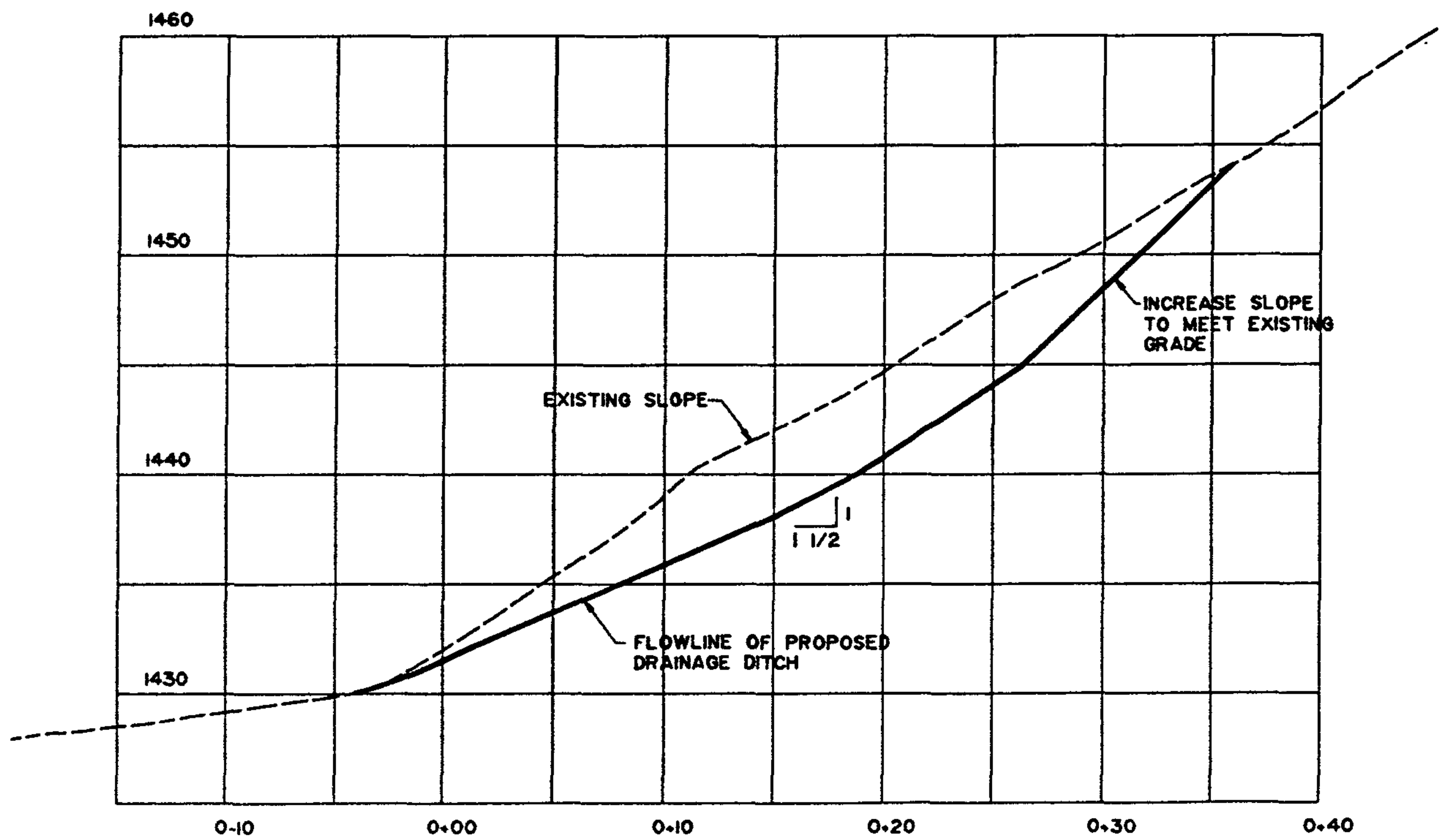
SCALE Ⓐ



37' SOUTH OF ℄

SECTION F

SCALE Ⓐ



52' SOUTH OF ℄

SECTION G

SCALE Ⓐ

ON MICROFILM

SCALE Ⓐ HORIZ. 5 0 5 10

VERT. 5 0 5 10

SCALE OF FEET

DESIGNED: TAY DRAWN: DTB TECH. REVIEW: DATE: 3/91	SUB SHEET NO. C-4	TITLE OF SHEET **WEST PORTAL CROSS SECTIONS** LOCATION STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	DRAWING NO. 423 25008 PKG. NO.	SHEET 4 OF 7

ELEVATION AT EAST PORTAL-EXISTING CONDITIONS

SCALE (A)

ELEVATION AT EAST PORTAL-PROPOSED IMPROVEMENTS

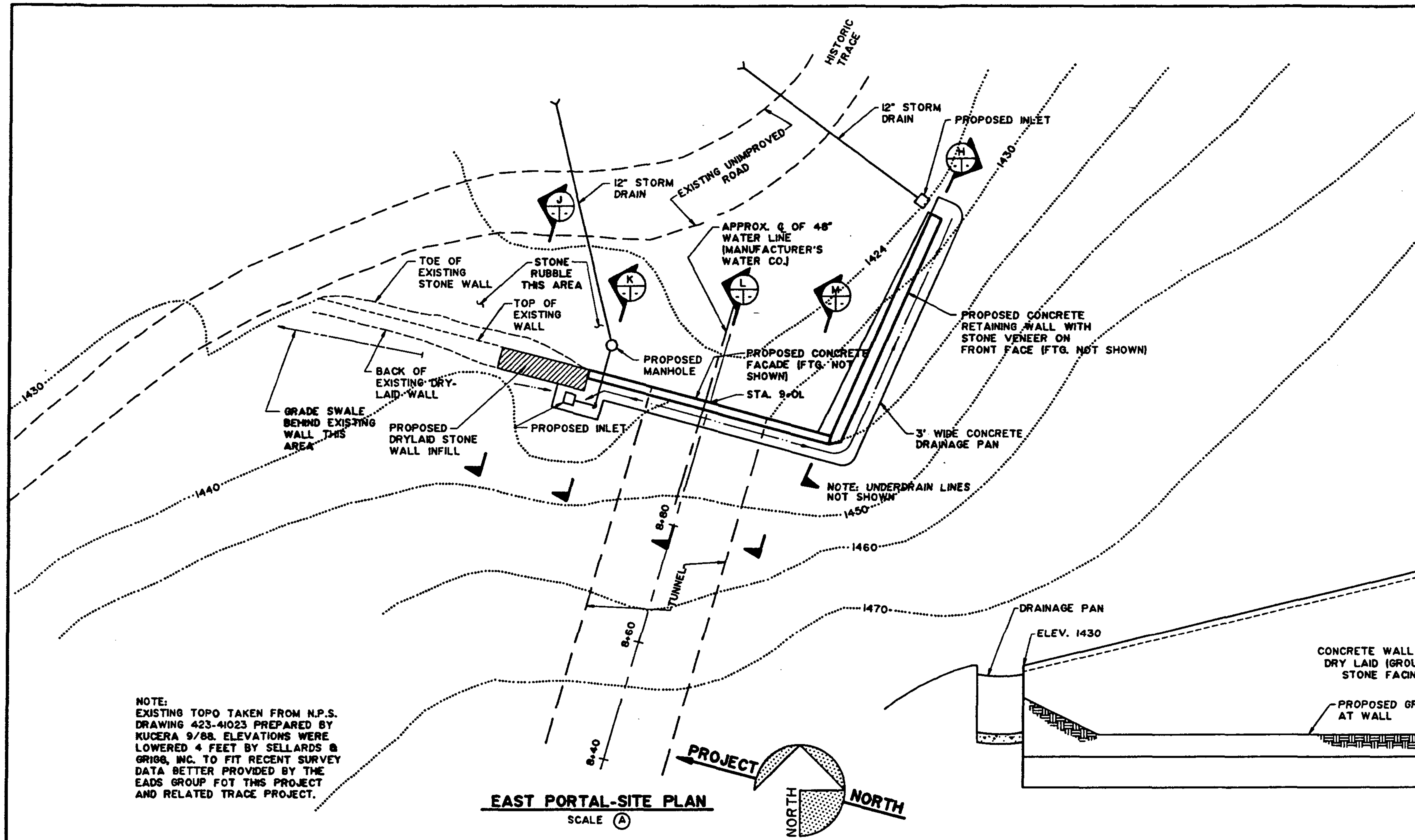
SCALE (A)

ON MICROFILM

SCALE (A) 4 0 4 8

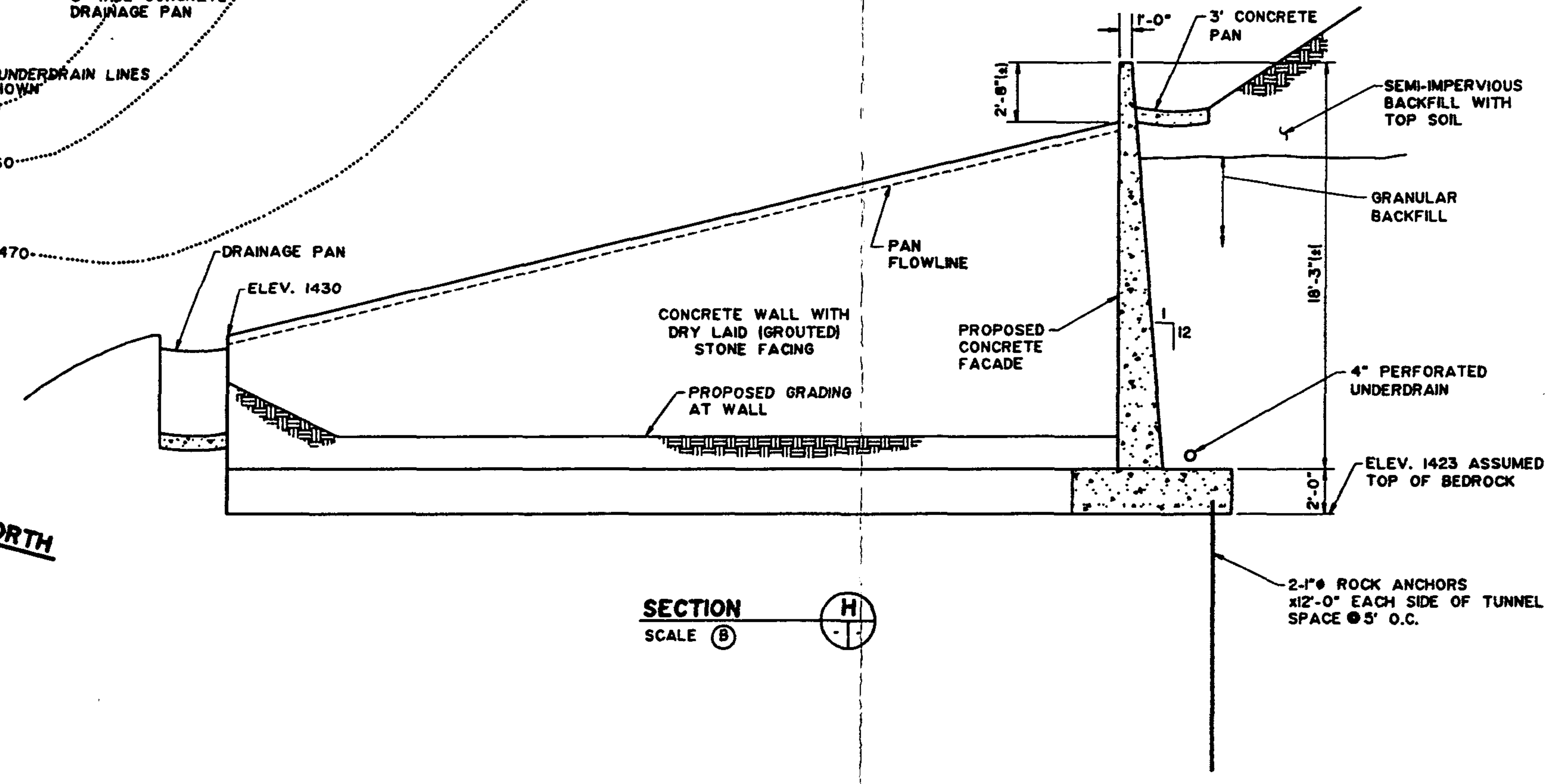
SCALE OF FEET

DESIGNED: TAY DRAWN: DTB TECH. REVIEW: DATE: 3/91	SUB SHEET NO. C-5	TITLE OF SHEET EAST PORTAL ELEVATIONS LOCATION STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	DRAWING NO. 423 25008 PKG. NO. SHEET 5 OF 7



NOTE:
EXISTING TOPO TAKEN FROM N.P.S. DRAWING 423-41023 PREPARED BY KUCERA 9/88. ELEVATIONS WERE LOWERED 4 FEET BY SELLARDS & GRIGG, INC. TO FIT RECENT SURVEY DATA BETTER PROVIDED BY THE EADS GROUP FOT THIS PROJECT AND RELATED TRACE PROJECT.

EAST PORTAL-SITE PLAN
SCALE Ⓐ



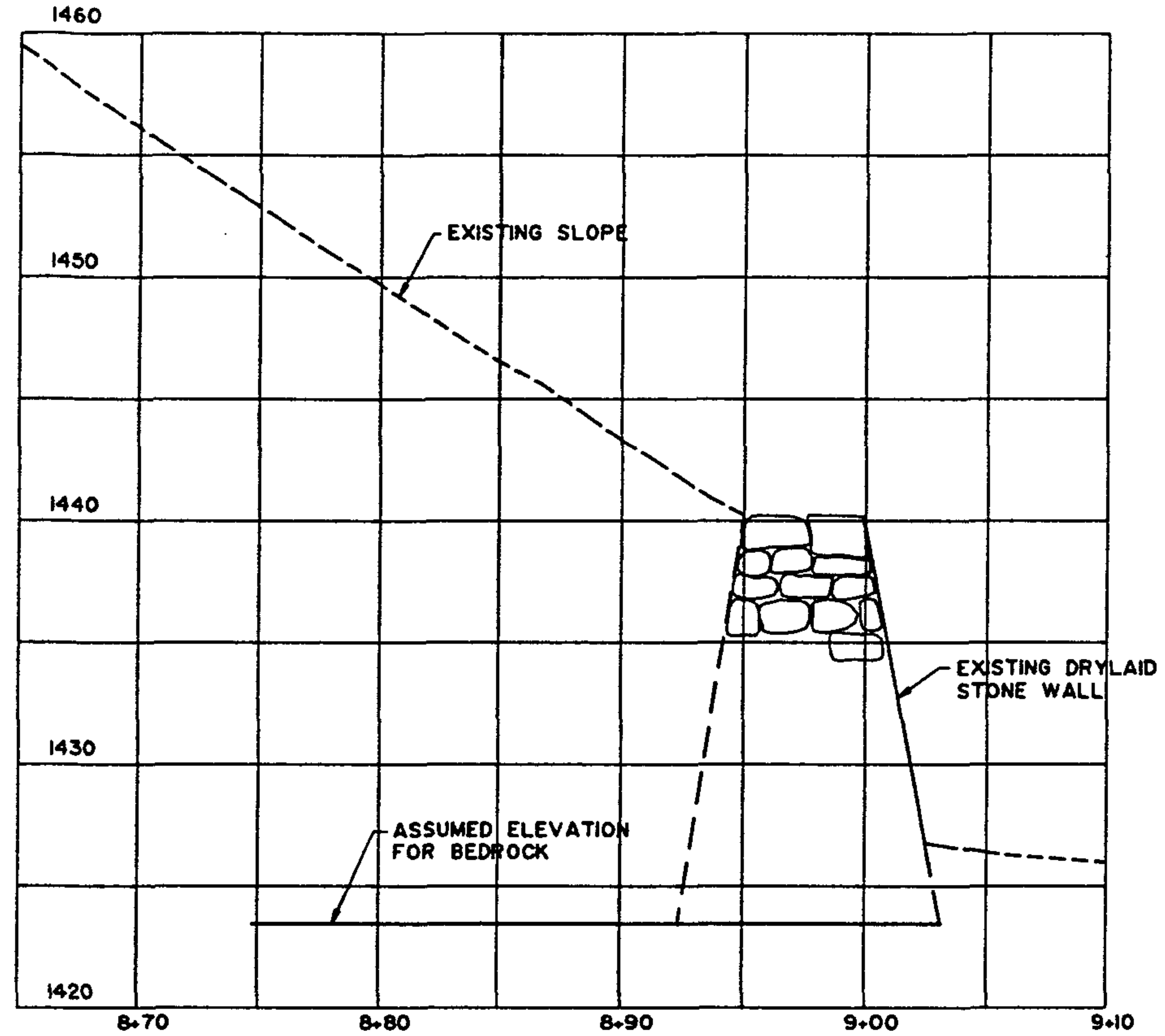
SECTION H
SCALE Ⓑ

ON MICROFILM

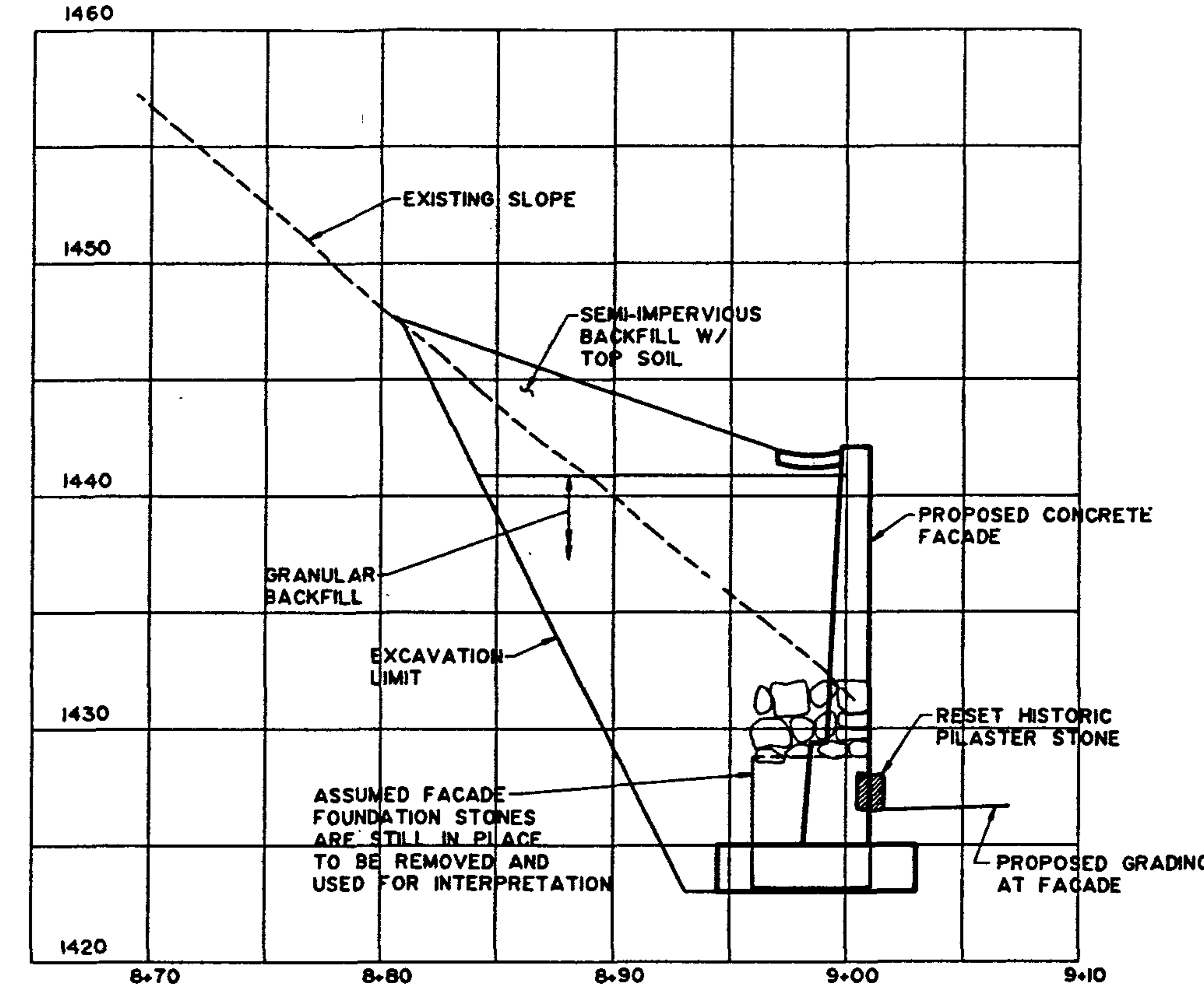
SCALE Ⓑ 4 0 4 8
SCALE OF FEET

SCALE Ⓐ 10 5 0 10 20
SCALE OF FEET

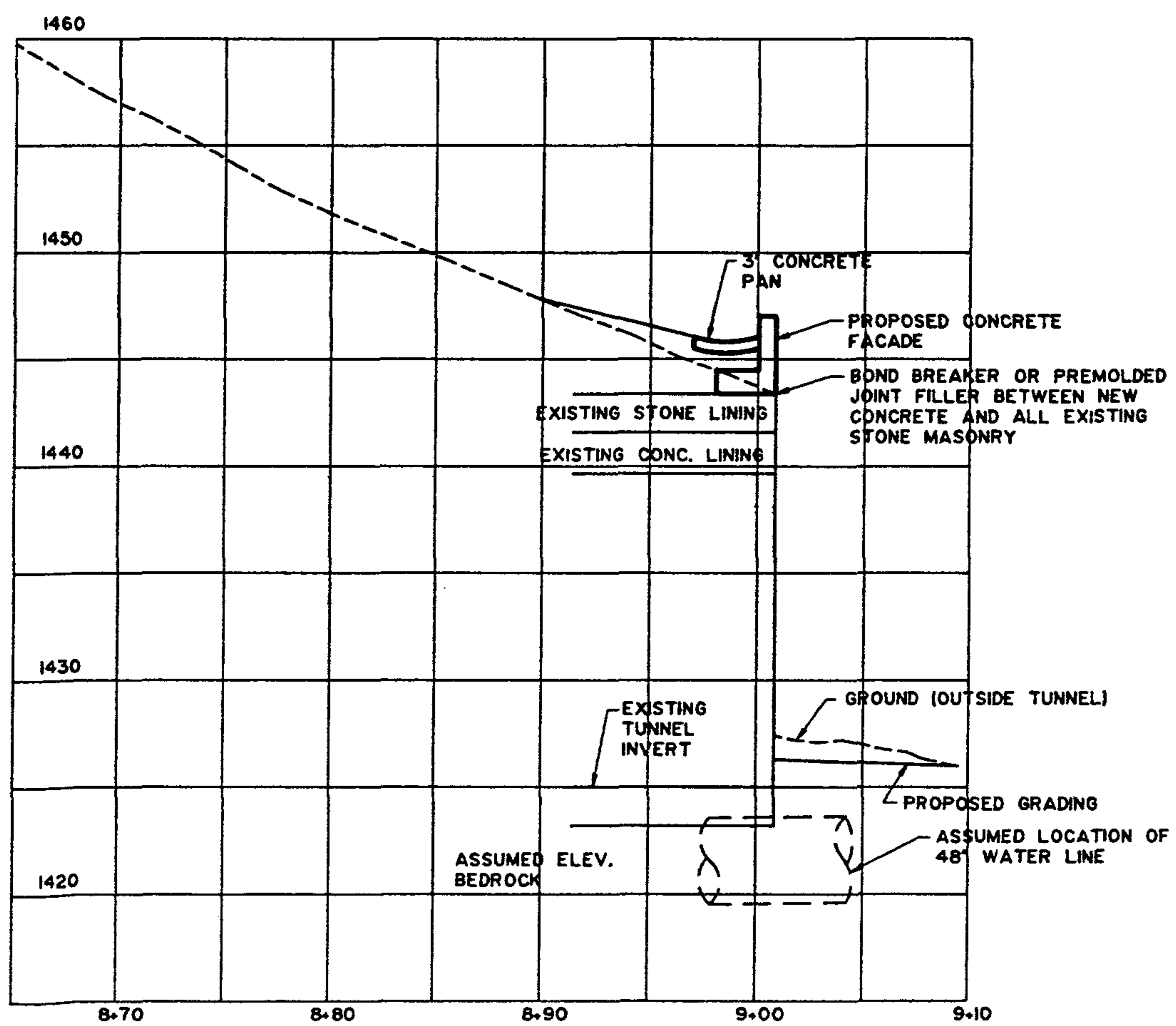
DESIGNED: TAY	SUB SHEET NO.	TITLE OF SHEET	DRAWING NO.
DRAWN: DTB	C-6	EAST PORTAL SITE PLAN	423 25008
TECH. REVIEW:		LOCATION	PKG. NO. — SHEET 6
DATE: 3/91		STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	OF 7



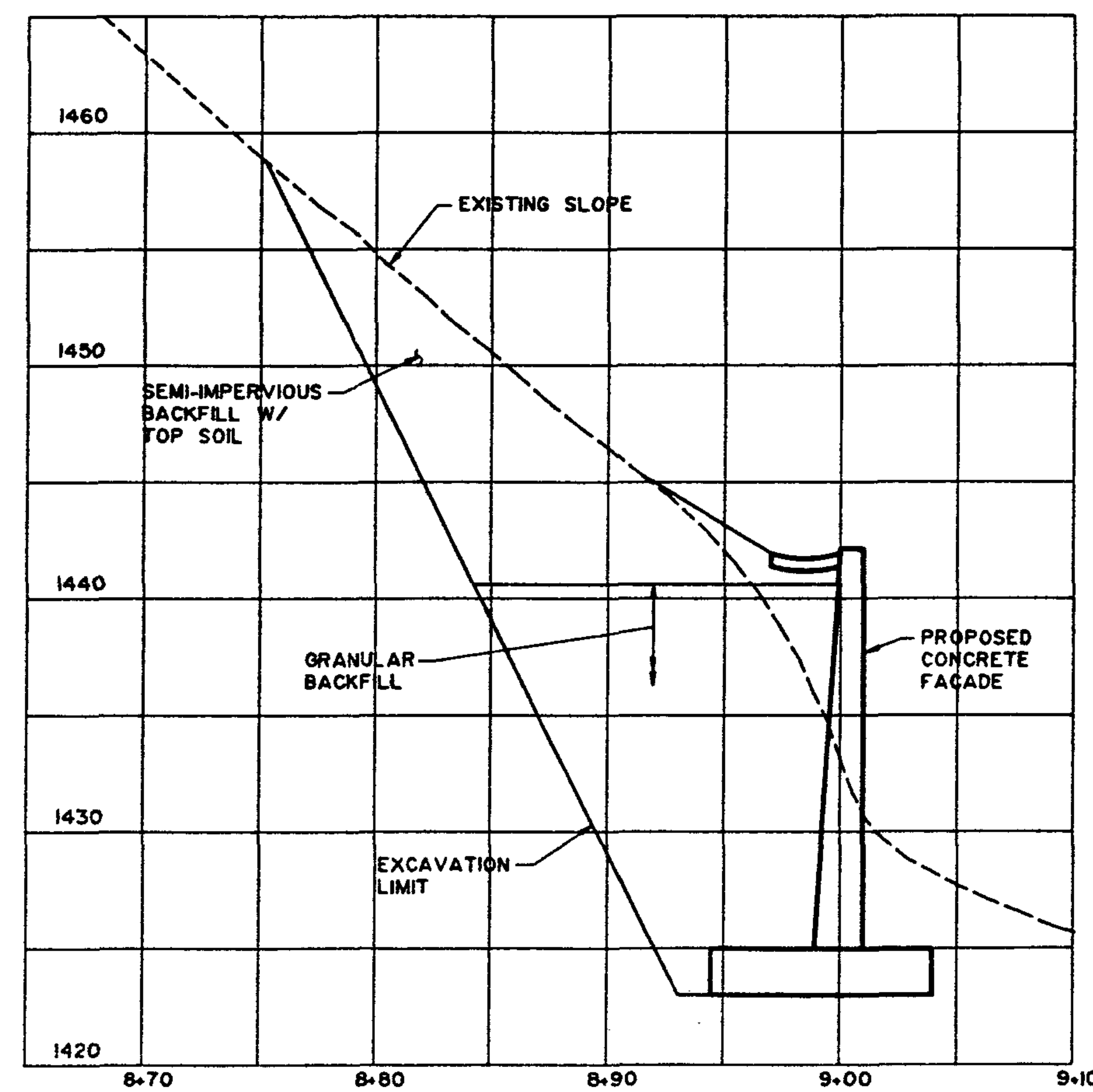
SECTION J
SCALE Ⓐ



SECTION K
SCALE Ⓐ



SECTION L
SCALE Ⓐ



SECTION M
SCALE Ⓐ

ON MICROFILM

SCALE Ⓐ HORIZ. 5 0 5 10
VERT. 5 0 5 10
SCALE OF FEET

DESIGNED: TAY	SUB SHEET NO.	TITLE OF SHEET	DRAWING NO. 423 25008
DRAWN: DTB	C-7	EAST PORTAL CROSS SECTIONS	PKG. NO.
TECH. REVIEW:		LOCATION STAPLE BEND TUNNEL NEAR MINERAL POINT, PENNSYLVANIA	SHEET 7 OF 7
DATE: 3/91			

VII. ANCILLARY ISSUES

A. Site Improvements

1. Water Vault Structure

The Manufacturer's Water Company (a part of Bethlehem Steel Company) has a 48" diameter water main that passes through the tunnel. The main purpose of the line is to provide a non-potable backup source of water for the Bethlehem Steel Company. It has been used only a few times during the past 30 years, but Manufacturer's Water Company is desirous of maintaining it in proper working order.

A water vault structure is located approximately 50 feet west of the west tunnel portal. It is positioned just off the centerline alignment for inclined plane No. 1 but fairly centered with respect to the axis of the tunnel. The structure is tapered with a square shape about 16.5' by 16.5' at the ground line and rises eight feet above the ground. It interferes with the good photographic opportunities for the west portal structure

Historically, there was a 42" diameter wood stave water line through the tunnel constructed in the very early 1900's. This pipe was replaced by a steel cylinder core 48" diameter concrete pipe with rubber "O" ring (Bureau of Reclamation R-2 type) gasketed joints constructed in the early 1940's. No construction drawings have been located by Manufacturer's Water Company to date. The wood stave line was removed when the concrete line was installed. Based on the cross-section excavated at STA 3+00, the concrete pipe would have been placed very close to the alignment and grade of the wood stave pipe. This was the only place where the pipe was excavated to measure its diameter and top elevation. Within the tunnel, the outside diameter of the pipe was measured to be about 48" at the springline (mid-height) of the pipe. There are two pieces of pipe that lie along the Bethlehem Steel Company industrial track near the bottom of inclined plane No. 1. They are supposed to be the same size as the pipe through the tunnel but they measured to have a 48" inside diameter with 5" thick walls.

The concrete water vault structure was built at the time the concrete water line was laid. The vault was built as an air and vacuum relief vault plus an overflow structure to control the gravity head on the pipe. The vault was constructed with a shaped channel invert to carry the water through the vault as an open conduit. During September, 1965, Manufacturer's Water Company closed the gap in the vault by installing a 48" diameter steel pipe through the vault. See Photo on Figure 10. The infill pipe contained a vertical tee with a 30" diameter flanged plate cover and 6" pipe with elbow and gate valve to act as an air release during filling the line. In operation, the 6" gate valve was to be closed to build up the line pressure and increase the flow of water through the line.

The man who operates the system does not operate it that way any more. He presently leaves the 6" gate valve full open at all times so the pipe functions as it did in the early 1940's when it was initially installed.

In a meeting with Manufacturer's Water Company on August 22, 1990, it was verbally agreed that the flanged cover plate along with the 6" elbow and valve could be unbolted from the vertical tee inside the vault and removed and the top slab of the vault lowered. Based on available photographs, it has been estimated that the top of the vault could be lowered 6.5 to 7.0 feet. Air venting of the vault would be required and an access manhole placed in the reconstructed top. By mounding up to the lowered structure, the visual impact of the vault structure for viewing the west portal would be nearly eliminated.

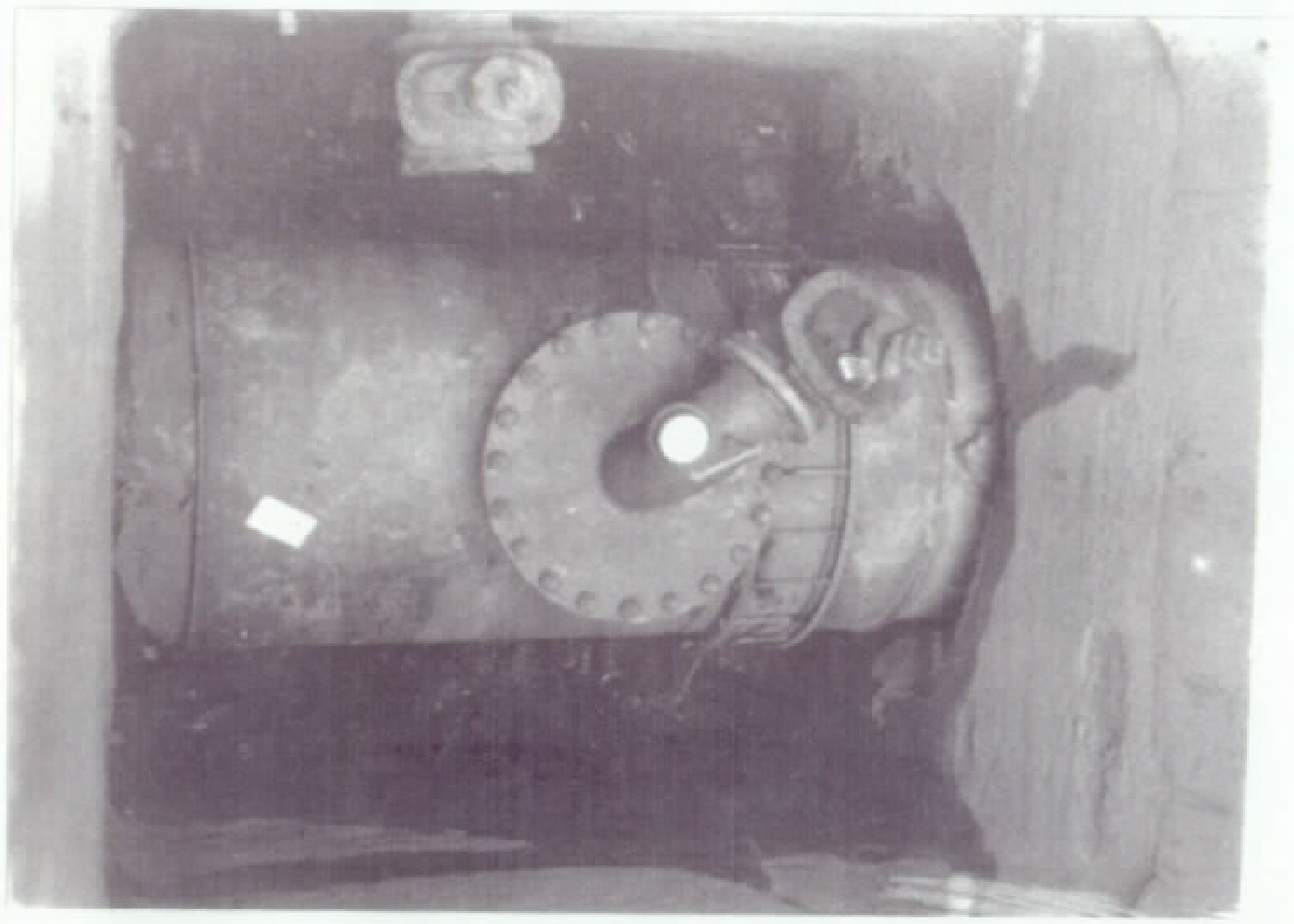
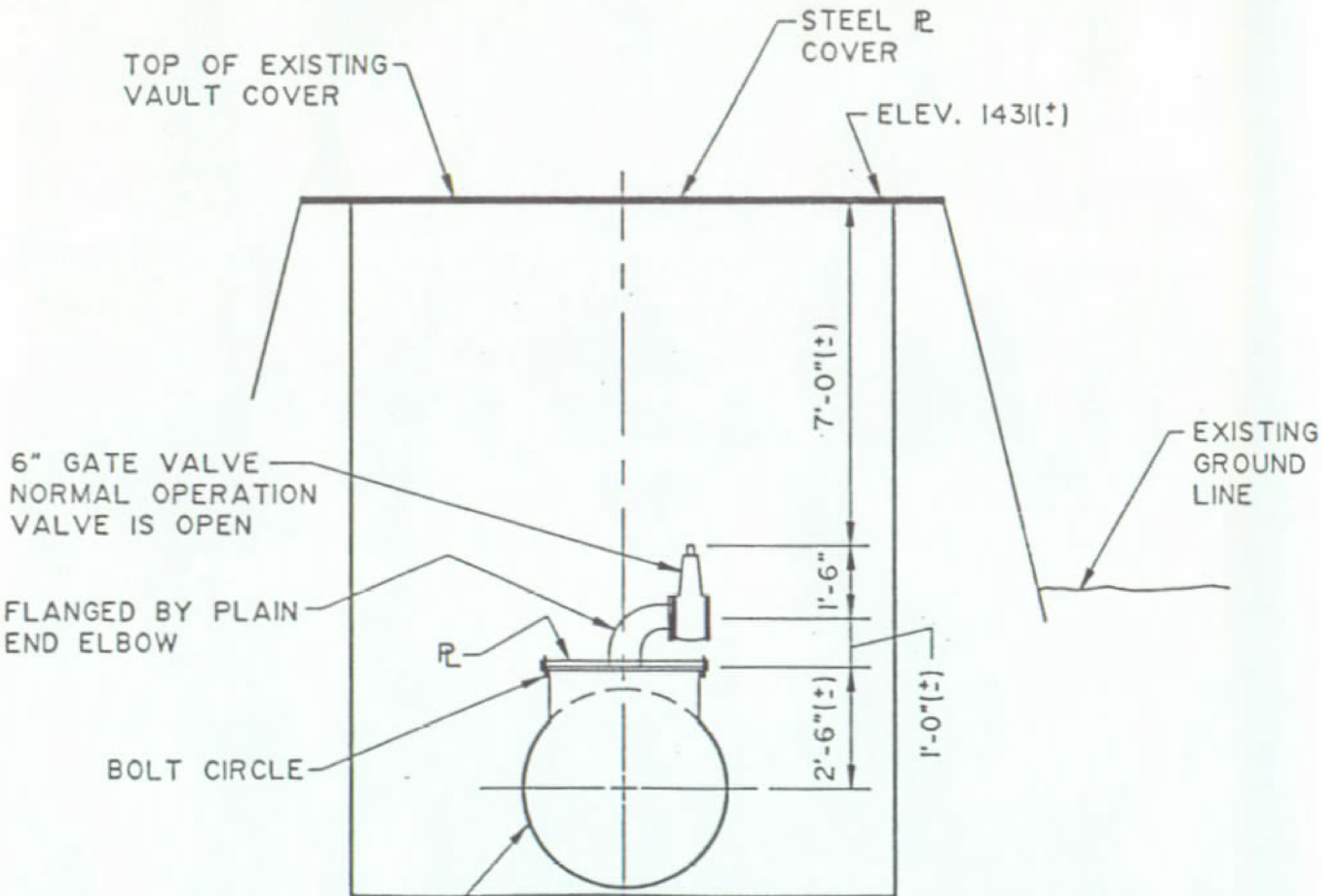


Photo courtesy of Manufacturers Water Co.



WATER VALVE STRUCTURE

SCALE: 1/4" = 1'-0"

FIGURE 10

Changing the alignment of the water line so that is would not run through the tunnel has been investigated by Manufacturer's Water Company. This option was determined to be too difficult and too costly to be practical. Thus, an agreement was reached that a permanent easement would be granted through the tunnel for the water line at the time the Department of the Interior acquires the land with the tunnel.

2. Electrical/Lighting

The interior of the tunnel is basically shades of gray that absorb the majority of light from any source. No measurements have been made on the absorption characteristics of the walls. However, from the description of the conditions given to an illumination engineer, he estimated that a minimum of 80% of the light would be absorbed. In an up-lighting condition, it is estimated that it would take 56 kilowatts of power (140-400 watt bulbs) to provide illumination with a minimum residual of 4 foot-candles of light at every point in the tunnel. Safety and specific interpretive opportunities would more appropriately establish values to be used in design.

Power is available along the Conrail alignment that parallels the historic trace along the north side. No formal contacts have been made regarding the actual availability of power since, at present, this subject is beyond the scope of this project. However, three alignments may be available to the site for consideration: 1) to bury a feed line along the 2.1 miles of the historic trace from County Road 11018; 2) to bury a feed line along Inclined Plane No. 1 from the southwest, or 3) to make a connection just north of the east portal and bury the line in the slope from the railroad right-of-way up to the historic trace. Alternatives 2 and 3 would probably require easements across land outside the proposed acquisition limits for this National Park Service project.

B. Tunnel Access

1. Public Access

Staple Bend Tunnel is located in Cambria County northeast of Johnstown, Pennsylvania. The site can be reached by taking U.S. Highway 219 to Summerhill and then traveling west on Pennsylvania State Route 3030 (County Road 11021) to Mineral Point. At Mineral Point turn south on County Road 11018 for approximately 0.5 miles to where the County Road intersects the historic railroad trace. Direct access to the tunnel is then westerly along the trace.

It is approximately 2.1 miles from County Road 11018 along the trace to the east portal of the tunnel. The alignment is somewhat curvilinear but generally follows a very gentle downward slope of 0.3%±. The existing condition of the trace is seriously overgrown with Japanese Bamboo planted in the past to revegetate the adjacent area and has become a nuisance plant growth along the route. Many of the stone sleepers are still in place. During the summer, water is present almost continuously along much of the trace, the water sources are from several active seeps and a number of locations which carry surface runoff from frequent rainfall. With the flat nature of the alignment, rainwater and water from other onsite sources has ponded in large potholes. With continued traffic, material becomes saturated and suspended causing the material to be pumped and splashed out of the holes. Some of these puddles have increased in size to the point of making travel in two wheel drive vehicles extremely difficult. Without improving the trace, construction traffic will be significantly slowed and will cause existing problems to worsen.

2. Public Safety

This section addresses the question of safety within the tunnel if it should be opened to the general public. The reference for these issues is Code of Federal Regulations 30: MINERAL RESOURCES (CFS 30). Specific concerns would include: a) tunnel integrity, b) air quality, c) fire safety, d) emergency situations, e) communications, and f) lighting.

a. Tunnel Integrity

Specific recommendations for insuring structural integrity of the tunnel are presented in Section 6 (Tunnel Remediation) of Attachment II. Assuming the tunnel will be closed to public access during the winter, the tunnel should be inspected each spring prior to reopening to the public. Any observations of distress or evidence of new rockfalls within the tunnel during the winter should be investigated and resolved prior to reopening the tunnel to public access.

National Park Service (NPS) staff should insure that the tunnel is properly ventilated prior to permitting public access. Generally this will involve opening the portal doors up to one-half hour before public entry to allow convective air exchange within the tunnel. This will not be required if the open grill closure is used and the infill panels are not in place.

CFR 30 Part 57, Subpart N addresses personnel protection. The NPS may have to provide hard hats for persons entering the tunnel.

b. Air Quality

Federal Regulation CFR 30 Part 57, Subparts D and G address air quality requirements for active tunnels/mines. Staple Bend Tunnel was competed in 1834 and being an inactive tunnel does not appear to fall under these regulations. Nevertheless, air quality should be a major concern for the NPS. With a 900-foot tunnel, ambient air quality can be readily controlled by allowing natural convective air circulation throughout the tunnel. This will require provision for opening both ends of the tunnel prior to public entry. The age of the tunnel and the lack of major carbonaceous layers in the exposed rock strata indicate there will be little if any methane gas in the tunnel. The only air quality problem would be carbon dioxide accumulation if unventilated during heavy use. The bedrock strata observed in the tunnel do not generally emit radon gases; however, this should be checked annually until five consecutive readings fail to indicate any problem. If radon gas is detected, regular ventilation should adequately protect the public against excess exposure.

c. Fire Safety

CFR 30 Part 57, Subpart C addresses fire safety. There are no combustible materials within the tunnel which could constitute a fire hazard. The only possible fire hazard risk would be if one or more of the exposed coal and/or carbonaceous shale beds should be deliberately ignited. Portable fire extinguishers should be provided at each entrance in case of emergency. Emergency exits at both portals would provide egress at a maximum 450 feet distance from within the tunnel.

d. Emergency Situation

CFR 30 Part 57, Subparts Q and N address safety and emergency situations. Federal regulations for mine safety require that an emergency plan be established and that NPS personnel be trained to respond to emergency situations identified in the plan. Since Staple Bend Tunnel is approximately 2 miles from the nearest access road, the plan should include procedures and identify resources such as med-evac helicopters to assist persons who may experience medical emergencies or accidents. First aid material must be available. Emergency access along the Conrail railroad track should be negotiated with Conrail.

e. Communications

CFR 30 Part 57, Subpart Q also addresses communication. If NPS personnel participate in any active interpretive effort within the tunnel, two-way radio communication should be provided with backup. The radios should be capable of reaching the nearest NPS base station or repeater station as well as the nearest medical facility.

f. Miscellaneous

The following areas offer additional interpretative opportunities at Staple Bend Tunnel:

* A short section of track could be installed in the tunnel using sleepers salvaged from along the railroad trace. This would show the tight space within the tunnel.

* A set of manikins could be placed to show the method of drilling the blast holes during construction. An area could be set up where visitors could use a hammer and drill on a piece of local bedrock to illustrate effort required to make a blast hole.

* Install spot lighting to highlight geologic features such as strata, faults, folds, or fossils.

* Prepare interpretive brochure with photos of key items for self-guided tours.

* Remnants of the wood stave penstock could be interpreted.

* The current Bethlehem Steel company water line could be interpreted.

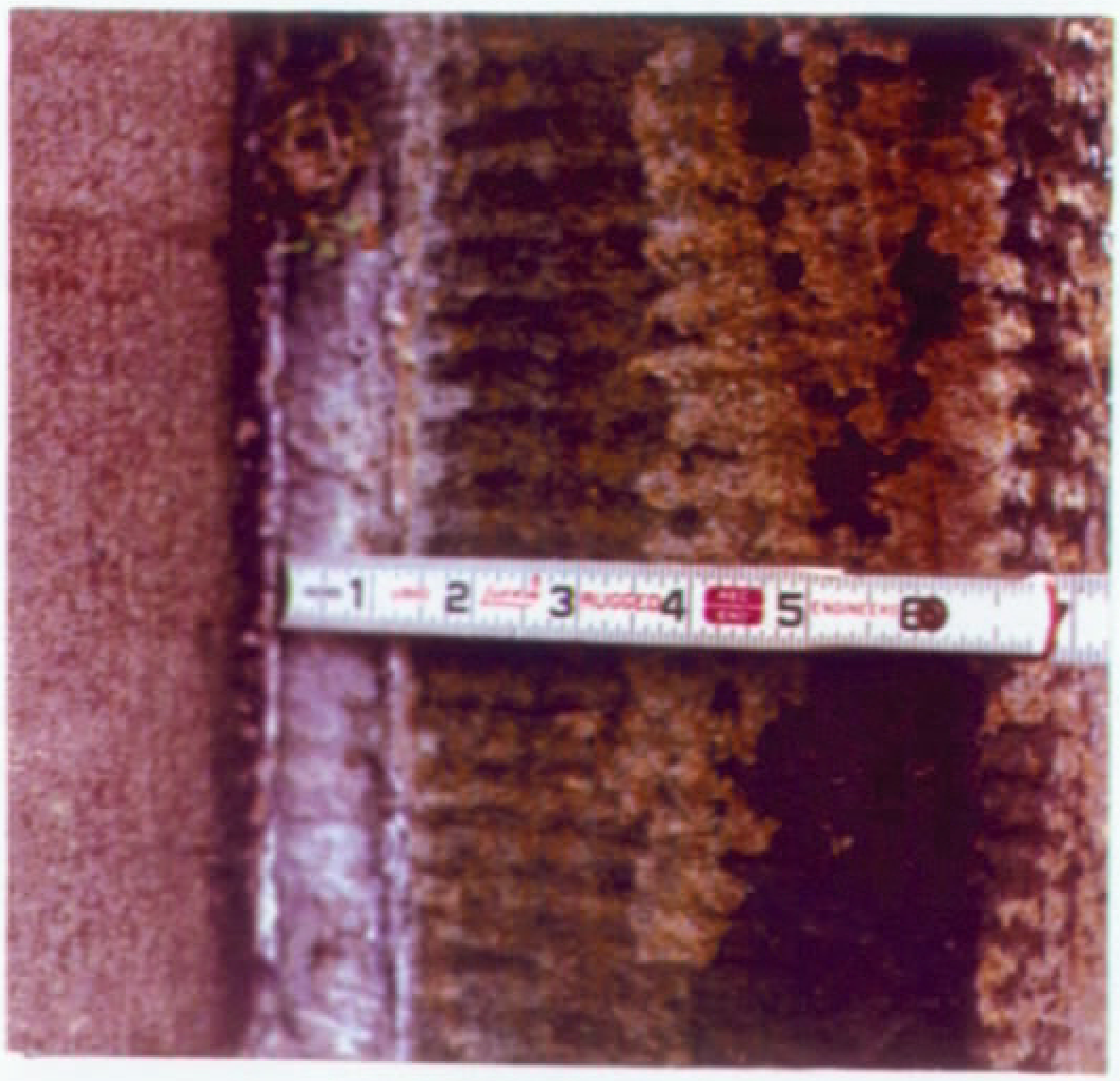
VIII. PHOTOGRAPHS

West End, 1990
View from north side.

West End, 1990
View of south side.

West End, 1990

West End, 1990
Back side of cornice.
Note vegetation.



West End, 1990
View of horizontal displacement of pilaster on south side of facade.

West End, 1990
Top view of water vault west of portal.

West End, 1990
View of displaced stone near top of north side.

1990
Station 8+50. Start of concrete lining. Note top was formed by tunnel liner plate and bottom was formed using boards.

East End, 1990
View of lined portion near east end at Sta. 7+50.

Unlined Rock Tunnel, 1990
View of bedrock tunnel looking west at Sta. 7+50.
Haze is from high humidity.

1990
Samples of painted and chiseled graffiti.

1990
Samples of painted and chiseled graffiti.

1990
Graffiti on parapet facing.

East End, 1990
View illustrates relative height of dry-laid retaining wall.

East End, 1990
View of north wingwall. Left eight feet were not part of original wall. Note evidence of fallen stone in foreground.

West End, 1990
Retaining walls are missing.
Grade has sloughed and covers portions of stone base.
Excessive growth aids deterioration.

West End, 1990
Retaining wall missing.

West End, 1990
Only portion of retaining wall remains.
Grade is substantially higher than historically.

West End, 1990
Parapet deterioration similar to 1920 photo.
South elevation has minor deterioration.
Column stones have been displaced outward ± 1".

West End, 1990
Water related structure partially obscures view and is built on historic foundation.

West End, 1990
Looking down incline.
Water related structure partially obscures incline.

West End, 1990
View from southwest.
Retaining wall less than half original height.
Plant growth aids deterioration.

West Facade, 1990
Parapet stone (north end).
Stone slightly dislodged. Mortarless joint. Edges are tooled.
Note slot in center (typical each parapet stone).

West End, 1990
View of rear of north end of parapet.
Note rotated stone.

West End, 1990
Elevation of north end.
Note pebbled texture and stone tooling.

West End, 1990
Rear of facade parapet.

West End, 1990
Parapet stones, north end wall.
Stone is rotated $\pm$ 70° from original.
One stone has fallen and lies at facade base.

West End, 1990
Parapet stones.
Cornice deterioration is consistent with historic photos of 1910 and 1920.
Broken stones appear to be sheared off by vandals.

East End, 1990
Overgrown Entry.
Concrete liner with concrete block infill.

East End, 1990
Concrete lining conforms to dislodged stones.
Rubble stone was used as retaining between arch stones
and column base remnant.

East End, 1990
Beveled and tooled arch stones.

East End, 1990
Dislodged arch stones at north side.
Stones have moved slightly from concrete lining indicating continued failure.

East End, 1990
Portion of original column base at north end with non-historic infill stone.

East End, 1990
View of arch construction at south side.
NOTE: Two stone lengths at beginning of coursing.
Earth cover is non-existent.

historic structure report

July 1990

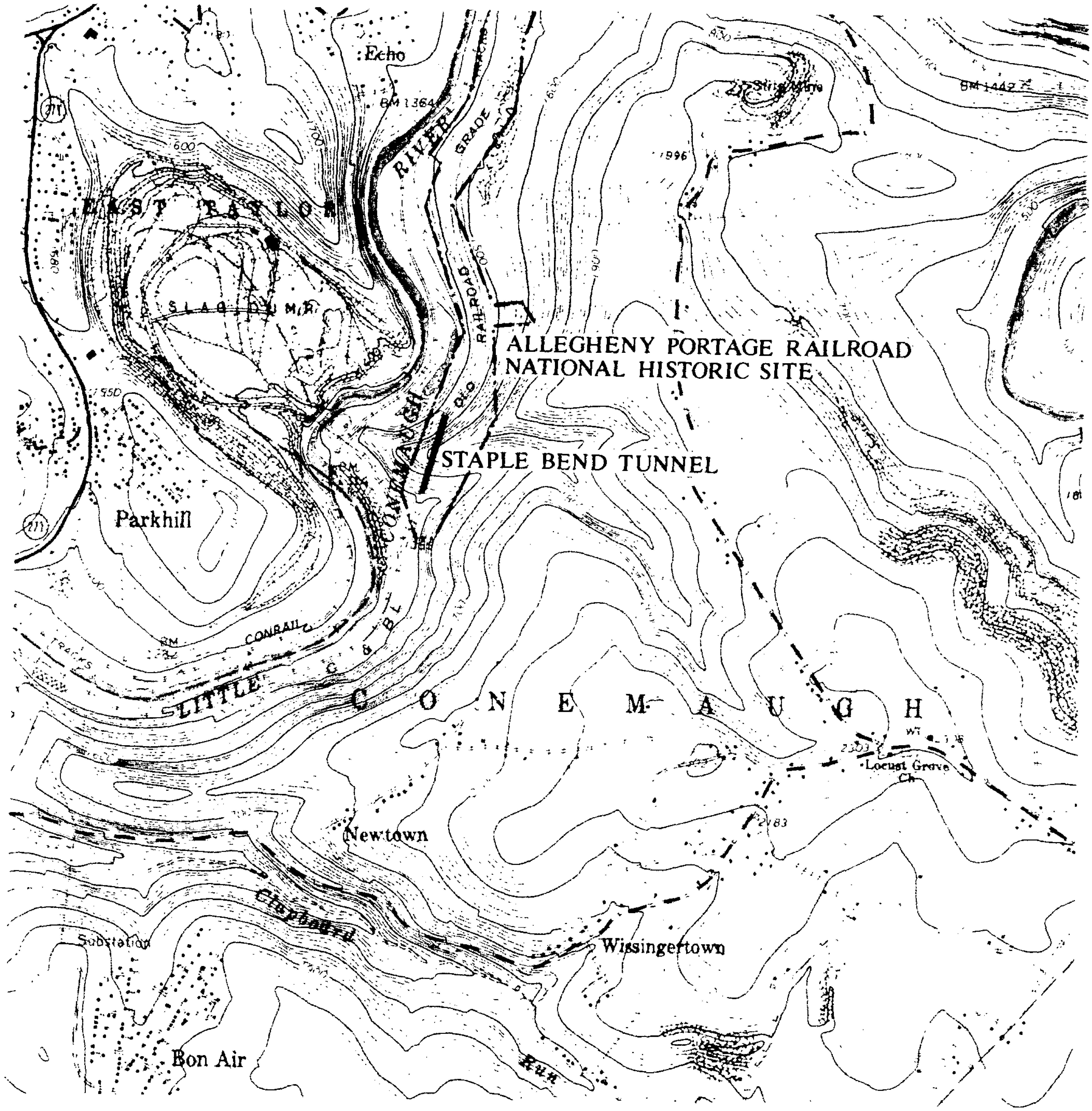
by A. Berle Clemensen

STAPLE BEND TUNNEL
ALLEGHENY PORTAGE RAILROAD
NATIONAL HISTORIC SITE • PENNSYLVANIA

UNITED STATES DEPARTMENT OF THE INTERIOR / NATIONAL PARK SERVICE

CONTENTS

ILLUSTRATIONS



LOCATION

STAPLE BEND TUNNEL
ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE

UNITED STATES DEPARTMENT OF THE INTERIOR • NATIONAL PARK SERVICE

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ACKNOWLEDGEMENTS

Numerous people gave of their time and aided me in researching and writing this report. My thanks go to Superintendent Peter Nigh and his staff at Allegheny Portage National Historic Site. I appreciated the efforts of Loretta Schmidt of the America's Industrial Heritage Project. In addition the people in the following agencies and institutions were very helpful: Cambria County Historical Society in Ebensburg, Indiana County Historical Society in Indiana, Altoona Public Library, the State Archives of the Pennsylvania Historical and Museum Commission in Harrisburg, the Transportation Division of the Smithsonian Institution, and the Library of Congress. Joyce Attebery of the Rocky Mountain Regional Office Library procured many interlibrary loan books for me. Jim Ellis of the Denver Service Center gave of his knowledge of tunnel construction. Mariette Dawson of the Denver Service Center Central Team aided with the translation of French.

INTRODUCTION

Staple Bend Tunnel is located on a two and one-half mile bend in the Little Conemaugh River in Conemaugh Township of Cambria County, Pennsylvania. Constructed between November 1831 and June 1833, it served as the first railroad tunnel in the United States. As part of the Allegheny Portage Railroad,the tunnel and that transportation line were viewed as an engineering marvel in their day. Although missing the facade on its east portal, the tunnel remains today as a reminder of a long past transportation era which permitted the rapid settlement of the nation's hinterland. Its link with the eastern seaboard helped to bring a redirection of trade and commerce away from shipping down the Ohio and Mississippi rivers and thus maintained Philadelphia as a leading port.

CHAPTER I

I. BACKGROUND

In the larger context of Pennsylvania transportation, the Staple Bend Tunnel on the Allegheny Portage Railroad formed only a small, but significant, segment of the total canal and railroad network developed by that state. It served on a communication route which connected Philadelphia with Pittsburgh. The tunnel's completion signaled the end of a long desired goal to link the state's western area to Philadelphia although a general movement to develop such a transportation system began only ten years prior to its attainment.

A. Early Communication Proposals

The earliest suggestion for the development of a route to western Pennsylvania was advanced before the American Revolution. This proposal in 1760 called for a Juniata-Allegheny passage. Nothing more, however, was heard of it until 1786. At that point a debate began on the desire for a canal to cross the state. The discussion reached sufficient magnitude by the fall of 1790 that one promoter, Daniel McClay, began to look for a water route from the mouth of Stony Creek (Johnstown) to Poplar Run on the Franktown branch of the Juniata River. In 1791, based upon his survey, a committee in the state legislature recommended that the Juniata, Little Conemaugh, and Kiskiminitas rivers be made navigable and that a portage road be built over the Allegheny Mountains. The suggestions were not taken seriously, however, until New York began to build the Erie Canal.[1]

Any thought of a canal languished until 1813. At that time David Reid and James Clark brought a canal proposal before the state legislature, but it did not receive favorable attention. It was not until ten years later in 1823 that a true canal craze began in Pennsylvania. In that year large sections of the Erie Canal opened. Reports circulated about the rapid development of the area through which that canal ran and the large toll revenues derived from the traffic. As a result, Pennsylvania delegates attended a canal convention in Washington, D.C. on November 6, 1823, but they did not succeed in getting federal aid for a state canal system.[2]

Although Pennsylvanians failed to attract federal aid, their efforts began to bear fruit in their state assembly. A mainline canal bill, which had been introduced in the legislature in 1823, was favorably reported in December of that year. It became law on March 27, 1824. The act provided for a three-member Board of Canal Commissioners who were charged with surveying three possible canal routes between Philadelphia and

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1. Julius Ruibin, "Canal or Railroad? Imitation and Innovation in the Response to the Erie Canal in Philadelphia, Baltimore, and Boston," vol. 51, part 7 of *Transactions of the American Philosophical Society* (Philadelphia: The American Philosophical Society, 1961), 19; Earl J. Heydinger, "Comprehensive History of the Pennsylvania Canal System, with Particular Attention to the Allegheny Portage Railroad, Portion: Plane #1, Staple Bend Tunnel and Long Level," (June 1966), IV:1-2, typescript in the Allegheny Portage National Historic Site library.

2. Thomas S. Reid, "Progressive Historian of Western Pennsylvanian," *Indiana Times* (Pennsylvania), March 1, 1882; Award L. Bishop, "Corrupt Practices Connected with the Building and Operation of the State Works of Pennsylvania," *Yale Review* 15(February 1907), 391; Robert McCullough and Walter Leuba, *The Pennsylvania Main Line Canal* (York, Pa.: The American Canal and Transportation Center, 1976), 18.

Pittsburgh. Governor John Schulze appointed the canal board four days later and asked that it make its survey report in December 1824.[3]

The canal commissioners began work immediately despite their inability to attract a competent engineer. Unable to reach a mutual agreement or meet the December deadline, the commissioners produced two reports. In February 1825 two members recommended a continuous canal between Philadelphia and Pittsburgh with a four-mile tunnel under the Allegheny summit. They proposed a route along the Susquehanna and Juniata rivers in the east and the Conemaugh and Allegheny rivers in the west. The third commissioner followed with a minority report in which he took exception to the route as too mountainous and particularly scoffed at the tunnel proposal.[4]

In the meantime a group composed principally of Philadelphia merchants organized the Pennsylvania Society for the Promotion of Internal Improvements in the Commonwealth in late 1824. Led by Mathew Carey, this organization espoused a railroad to connect Philadelphia with Pittsburgh. In their zeal to develop a railroad, the group helped organize an Internal Improvement Convention which met at Harrisburg from August 4 to 6, 1825. The preponderance of the delegates, however, favored a canal. Although the railroad proponents continued to press their position, they lost their impetus when the chief railroad exponent, Mathew Carey, switched to favor a canal.[5]

Although popular sentiment throughout the state favored a canal, there was little agreement on the canal route. As a result of petitions from various areas of the state, the legislature passed a new act which became law on April 11, 1825. It established a five member Board of Canal Commissioners. Organized in July, this board was charged with examining seven possible canal routes between the east and west areas of the state and selecting one route for construction.[6]

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3. Rubin, "Canal or Railroad?" 20; William Bender Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," in *Annual Report of the Secretary of Internal Affairs of the Commonwealth of Pennsylvania for the Year Ending June 30, 1899, Part IV: Railroad, Canal, Navigation, Telegraph and Telephone Companies* (Philadelphia: Wm. Stanley Ray, 1900), XLI; *Tenth Census of the United States: Transportation* (Washington, D.C.: Government Printing Office, 1883), 736-737; Harry A. Jacobs, "The Old Juniata Canal and Portage Railroad," in George A. Wolf, ed., *Blair County's First Hundred Years, 1846-1946* (Altoona, Pa.: The Mirror Press, 1945), 159; George Johnson, Earl Giles, and Ralph Michaels, "Johnstown and the Pennsylvania Canal, in Karl Berger, ed., *Johnstown: The Story of a Unique Valley* (Johnstown, Pa.: Johnstown Flood Museum, 1985), 215; Tarring S. Davis *A History of Blair County*, vol. 1 (Harrisburg, Pa.: National Historical Association, Inc., 1931), 48; Hubertis M. Cummings, *Pennsylvania Board of Canal Commissioners' Records* (Harrisburg, Pa.: Bureau of Labor Records, 1959), 1; Howard M. Jenkins, ed., *Pennsylvania: Colonial and Federal*, vol. 3 (Philadelphia: Pennsylvania Historical Publishing Assn, 1903), 279; McCullough and Leuba, *The Pennsylvania Main Line Canal*, 18; J.E. Watkins, "The Portage Railroad and the New Portage Railroad," 147, unpublished manuscript (1896) in Allegheny Portage Railroad National Historic Site library; Thomas A. Logue, "History of Old Portage Railroad," *Altoona Mirror* (Pennsylvania), February 13, 1939; Thomas J. Chapman, *The Valley of the Conemaugh* (Altoona, Pa.: McCrum & Dern, 1865), 79.

4. Rubin, "Canal or Railroad?" 20-21; Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," xlii-xliii; Jacobs, "The Old Juniata Canal and Portage Railroad," 159; Jenkins, *Pennsylvania Colonial and Federal*, III:279; McCullough and Leuba, *The Pennsylvania Main Line Canal*, 18; Logue, "History of Old Portage Railroad."

5. McCullough and Leuba, *The Pennsylvania Main Line Canal*, 18; Rubin, "Canal or Railroad?" 25-29; Logue, "History of Old Portage Railroad;" Chapman, *The Valley of the Conemaugh*. 79.

6. Cummings, *Pennsylvania Board of Canal Commissioners' Records*, 2; Rubin, "Canal or Railroad?" 25; Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," xliii; Jenkins, *Pennsylvania: Colonial and Federal*, III:280; Logue, "History of Old Portage Railroad."

The 1826 legislative session opened with a great desire to begin construction on a canal. Although the canal board had not made its report on the survey of the seven routes, the legislature passed a canal construction act which became law on February 25, 1826. it called for an uninterrupted waterway from Philadelphia to Pittsburgh to be built at state expense and to be called the Pennsylvania Canal. Over three months later, on June 3, the canal commissioners reported to Governor Schulze that the Juniata route was their choice, but they recommended against a tunnel under the Allegheny Mountain. In lieu of a tunnel they proposed a portage railroad.[7]

Although canal construction began on July 4, 1826, further survey work was needed. A decision also had not been made on whether to build a tunnel under the Allegheny Mountain or a portage railroad over it. Canvass White, as engineer in charge, conducted another survey in the latter part of 1826 to solve the Allegheny Mountain dilemma. He recommended a portage railroad. His assistant, George Olmstead, supported a railroad, but reported on January 30, 1827 that he did not have enough time to determine a route. Despite this opinion no decision was reached in 1827 because the public still favored an all-water route.[8]

The thoughts of the Canal Board obviously tended toward a portage railroad over Allegheny Mountain. On March 26, 1828, they assigned one of their members, Abner Lacock, the task of having a portage survey done. He appointed Nathan Roberts, an engineer, to accomplish the survey. Beginning June 14, 1828, Roberts made an extensive examination of Allegheny Mountain. He concluded in his report on December 1 of that year that a double portage composed of a side-by-side railroad and turnpike was needed. When Roberts resigned after presenting the report, Moncure Robinson was appointed on December 8, 1828 to replace him. The canal commissioners asked Robinson to examine the potential of a portage railroad composed of lifts and levels with a macadamized road parallel to it. After making his survey in 1829, Robinson reported on November 21 that he wished to establish a portage railroad with a system of planes and a one-mile long tunnel at the top. It was to be thirty-eight miles long, while his route for the turnpike had a fifty-mile length.[9]

Neither the Board of Canal Commissioners, the governor, nor the legislature could accept Robinson's plan without confirmation by other civil engineers. As a result, Governor George Wolf signed a legislative act on March 17, 1830, which requested more information on Robinson's proposal. With this authorization the canal board hired Major D.B. Douglass and Lt. Col. Stephen H. Long of the United States Corps of Engineers to make a further

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7. Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," xliii; *Tenth Census of the United States: Transportation*, 737; Cummings, *Pennsylvania Board of Canal Commissioners' Records*, 2; McCullough and Leuba, *The Pennsylvania Main Line Canal*, 20; Logue, "History of Old Portage Railroad;" Jacobs, "The Old Juniata Canal and Portage Railroad," 159; William B. Sipes, *The Pennsylvania Railroad: Its Origins, Construction, Condition, and Connections* (Philadelphia: The Passenger Department, 1875), 6.

8. Davis, *A History of Blair County*, I:48; Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," XLV; Logue, "History of the Old Portage Railroad."

9. Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," xlvi-xlvii; Logue, "History of Old Portage Railroad;" Watkins, "The Portage Railroad and the New Portage Railroad," 149; Heydinger, "Comprehensive History of the Pennsylvania Canal System," IV:4; Rubin, "Canal or Railroad?" 58; Michael Chevalier, *Histoire et Description des Voies de Communication aux Etats Unis et des Travaux d'art qui en Dependent*, vol. I (Paris: Charles Gosselin, 1840), 395.

investigation. Douglass was replaced by Major John Wilson in June 1830. When they reported their conclusions in the fall, Long and Wilson recommended that only a railroad be built. In their view it would use a route which crossed Blair's Gap summit and descended to Johnstown through the Laural Run and Little Conemaugh valleys. They saw no need for the mile-long summit tunnel which Robinson wanted, but they did contemplate a tunnel approximately 1,000 feet long at one of the bends of the Little Conemaugh River.[10]

Moncure Robinson opposed Long and Wilson's position that a summit tunnel was not necessary. He submitted that the tunnel would reduce the route by five miles and eliminate curves on inclined planes. The canal commissioners accepted Robinson's view except for the summit tunnel. As a result, the legislature passed "An Act to Continue the Improvement of the State by Canal and Railroads" which Governor Wolf signed on March 21, 1831. The final portage route, however, still had not been settled. This was not established until after Chief Engineer Sylvester Welch and his assistant Moncure Robinson began work with their crew on April 8, 1831. They finalized a route on May 20 which was 36.65 miles long.[11]

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10. Logue, "History of Old Portage Railroad; Wilson, "The Evolution, Decadence, and Abandonment of the Allegheny Portage Railroad," xlvii-xlix; Rubin, "Canal or Railroad?" 58; George H. Burgess and Miles C. Kenney, *Centennial History of the Pennsylvania Railroad Company* (Philadelphia: The Pennsylvania Railroad Co., 1949), 10-11; Hubertis Cummings, "The Allegheny Portage Railroad," *Historic Pennsylvania Leaflet No. 9* (Harrisburg: Pennsylvania Historical and Museum Commission, 1957), 2.

11. Wilson, "The Evolution, Decadence, and Abandonment of the Allegheny Portage Railroad," xlix-l; Johnson, Giles, and Michael, "Johnstown and the Pennsylvania Canal," 216; McCullough and Leuba, *The Pennsylvania Main Line Canal*, 30, 62; Logue, "History of Old Portage Railroad;" Cummings, "The Allegheny Portage Railroad," 2; Rubin, "Canal or Railroad?" 58; Jacobs, "The Old Juniata Canal and Portage Railroad," 160.

CHAPTER II

II. THE TUNNEL AT STAPLE BEND

On March 30, 1831, nine days after Governor Wolf signed the act to construct the Allegheny Portage Railroad, that segment was annexed to the western division of the Pennsylvania Canal. As principal engineer for this area, Sylvester Welch, with his assistant Moncure Robinson, soon proceeded to locate a line for the railroad from Johnstown to Hollidaysburg. Upon determining the route, the state appropriated to itself a strip of land 120 feet wide along the entire length of the railroad. Welch divided the 36.65-mile distance into thirty-five sections and began to prepare contracts for the part which ran from Johnstown to the summit. Contractors submitted their bids and awards were made at Ebensburg on May 25, 1831. Corruption often proved a factor in contractor selection, for the canal commissioners frequently awarded contracts to political party supporters or to friends.[1]

Welch located the proposed tunnel at the Staple Bend of the Little Conemaugh River and assigned it to section seven. He described it as

> Section 7 -- 3600 feet long. The line leaves the creek at the beginning of the section [foot of inclined plane No. 1]. It passes along the inclined surface of the hill 1300 feet to Deep Run Hollow, thence crosses the hollow, 400 feet, to the south end of the projected tunnel. On the last mentioned distance the embankment will be deep. At one point, it will equal 50 feet. The materials to form it will be taken principally from the tunnel and from the deep cutting at the end of it.
>
> The tunnel is to be 900 feet long. Its transverse section to equal a prism 16 by 20 feet. The width at bottom to be 20 feet. At the ends of the tunnel, some masonry will be required, but appearances indicate that the rock is sufficiently hard and strong within not to require arching.
>
> The form of the roof or top of the vault will be determined by the character of the rock. The hill at the summit is 195.77 feet above the floor of the tunnel or grade of the road.[2]

Welch also noted that the remainder of the section going north from the tunnel would require a heavy embankment for about 400 feet. He concluded that the material for this embankment would come partly from the tunnel.[3]

On May 25, 1831, J. and E. Appleton won the contract to construct section seven. The Canal Board specified that the tunnel be completed by May 1, 1832. This unrealistic date was later changed. Samuel Jones, the immediate superintendent of construction,

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1. Sylvester Welch to the Board of Canal Commissioners of Pennsylvania, May 23, 1831, Reports and Miscellaneous Documents, Board of Canal Commissioners, Allegheny Portage Railroad, Box 8, Reports and Miscellaneous Documents 1829-43, Record Group 17, Records of the Bureau of Land, Pennsylvania Historical and Museum Commission, Harrisburg, Pennsylvania (hereafter cited as RG 17); *The Sky* (Ebensburg, Pennsylvania), December 31, 1831; Bishop, "Corrupt Practices Connected with the Building and Operation of the State Works of Pennsylvania," 400-402; Logue, "History of Old Portage Railroad;" Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," L.

2. Sylvester Welch to the Board of Canal Commissioners of Pennsylvania, May 23, 1831.

3. Ibid.

chose Solomon Roberts, an engineer, to oversee the work on that section. In June the Appletons began work on the section leading to the tunnel. It was not until November 21, 1831, however, that work began on the tunnel with excavation occurring at both ends. The following day it snowed and the weather turned intensely cold. Despite the inclement conditions the men continued to work.[4]

Prior to construction, the Appletons built a housing facility at the tunnel site for their workforce. Since tunnel construction was in its infancy in the United States, the men hired to dig the tunnel would have been miners. The skilled workers were undoubtedly of Welsh extraction while the labor force no doubt consisted of Irishmen. The men were paid $13.00 per month plus board and room.[5]

Work on the tunnel progressed with increasing cubic yards of rock removed each month until March 1832. In November 1831, 140 cubic yards of rock had been taken from the tunnel. This figure increased to 560 cubic yards the next month, followed by 740 cubic yards in January 1832. February 1832 saw 900 cubic yards removed. Then, in March, the men excavating in one end encountered a softer rock than anticipated. A portion of this rock would crumble when exposed to the atmosphere. While one author, in writing about the tunnel, stated that it was cut through slate, another stated that the rock was sandstone. The latter individual was undoubtedly correct considering that the geology of the area indicated more sandstone than slate. The soft area encountered probably had its cohesiveness leached from it by water. At any rate, work slowed as more timbering was required to support the roof. Only 370 cubic yards of material were removed from the tunnel in March. Still encountering soft rock in part of April, the excavations proceeded at a slower pace with 550 cubic yard of rock removed.[6]

Although the original plan called for placing a stone arch extending 150 feet on each end of the tunnel, the soft rock caused a temporary change in plans. Sylvester Welch felt that they should be prepared to arch the remaining area with brick. This situation would make the tunnel more costly. It would require additional excavation to admit the additional brick arch which Welch estimated would cost $4,924.50. He thought it would require another $13,132.50 for the arch itself. He, however, noted that "if in the further prosecution of the work, the rock should become harder and less liable to fall to

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4. Wilson, The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," liv; Work Estimate for Section 7 by J. and E. Appleton, July 27, 1831, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 3, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, April 7-November 11, 1831, Record Group 17, Records of the Bureau of Land, Pennsylvania Historical and Museum Commission, Harrisburg, Pennsylvania; Work Estimate for Section 7 by J. and E. Appleton, December 1, 1831, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 4, Allegheny Portage Railroad, Engineers Accounts, Estimates Work Receipts, November 25, 1831-May 21,1832, RG 17; *The Sky* (Ebensburg, Pennsylvania), December 8, 1831; Logue, "History of Old Portage Railroad."

5. Henry S. Drinker, *Tunneling, Explosive Compounds, and Rock Drills* (N.Y.: John Wiley and Sons, 1882), 27; Heydinger, "Comprehensive History of the Pennsylvania Canal System," V:8.

6. Work Estimates for Section 7 by J. and E. Appleton, December 1, 1831, December 31, 1831, February 1, 1832, March 7, 1832, April 4, 1832, and May 10, 1832, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 4, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, November 25, 1831-May 21, 1832, RG 17; Sylvester Welch to James Clarke, President of the Board of Canal Commissioners of Pennsylvania, May 16, 1832, Board of Canal Commissioners, Allegheny Portage Railroad Reports and Miscellaneous Documents, Box 8, Reports and Miscellaneous Documents 1829-43, RG 17; Drinker, *Tunneling, Explosive Compounds, and Rock Drills*, 27; Chevalier, *Historie et Description des Voies de Communication*, I:402.

pieces, a part of the arch may be dispensed with, and the expense of construction reduced."[7]

About the time that Welch wrote to James Clark in May 1832 expressing his concern over the soft rock, the construction crew again encountered firmer rock and digging once more increased. In that month fifty men were employed in the tunnel working round the clock. They cut about eighteen inches from the tunnel face each twenty-four hours. The cubic yards dug for May more than doubled over the previous month, reaching 1,360. By May 23 the tunnel reached 184 feet on the west end. At that point Solomon Roberts decreed that work should begin on the dressed stone arch. This work, however, did not begin until July.[8]

Although work slowed in June 1832, probably due to more soft rock, it began with ever increasing excavation in July. While June found only 670 cubic yards removed, July's output was boosted to 1,290 cubic yards. August's production increased even more to 1,470 cubic yards only to be exceeded with 1,604 cubic yards for September as the inner portion of the tunnel proved to be of sufficiently hard rock to eliminate problems. Again, excavation dipped in October to 1,134 cubic yards, but it reached its greatest extent in November with 1,872 cubic yards. On December 21, 1832 the workmen broke through the final barrier and opened the tunnel. Samuel Jones notified the canal commission of the event and observed that "the shafts have met with great precision."[9]

Having opened the tunnel, the amount of cubic yards of rock removed began to drop and the focus turned toward completing the arch and the facade at each entrance. The December 1832 rock removal amounted to 1,104 cubic yards. Aggregate cubic yardage dropped to 886 in January 1833 and to 150 the next month as excavation was almost completed. No rock was removed in March, and only a final 100 cubic yards were removed in April as cleanup occurred.[10]

Although the tunnel excavation was completed in April 1833, the arch and entrance facades remained incomplete. Work had begun to arch or line the tunnel for 150 feet from each entrance in July 1832, but it progressed slowly for the first several months. This arch consisted of eighteen-inch thick dressed stone. The source of this stone remains unknown, but it undoubtedly came from the area. The arch work continued into April 1833. Upon

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7. Sylvester Welch to James Clarke, President of the Board of Canal Commissioners of Pennsylvania, May 16, 1832.

8. Work Estimate for Section 7 by J. E. Appleton, July 5, 1832, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 5, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, May 30, 1832-November 17, 1832, RG 17; Heydinger, "Comprehensive History of the Pennsylvania Canal System," V:8.

9. Work Estimates for Section 7 by J. and E. Appleton, July 5, 1832, August 3, 1832, September 1, 1832, October 1, 1832, October 31, 1832, December 10, 1832, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 5, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, May 20, 1832-November 17, 1832, RG 17; Samuel Jones to James Clarke, President of the Board of Canal Commissioners, December 22, 1832, Board of Canal Commissioners, Allegheny Portage Railroad, Reports and Miscellaneous Documents 1829-43, RG 17; Heydinger, "Comprehensive History of the Pennsylvania Canal System," V:9; *The Ebensburg Sky* (Pennsylvania), December 27, 1832.

10. Work Estimates for Section 7 by J. and E. Appleton, January 3, 1833, February 11, 1833, March 11, 1833, April 9, 1833, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Box 6, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, December 20, 1832-August 30, 1833, RG 17.

its completion the cut stone entrance facades were begun. They were completed in June 1833 and with the end of that work, Staple Bend Tunnel was finished. As the first railroad tunnel in the United States, it measured 901 feet long, twenty feet wide, and nineteen feet high within the arch. The construction cost amounted to $37,498.85. Of that figure $21,903 was paid for the removal of 14,900 cubic yards of rock during excavation. The contractor received $1.47 per cubic yard. The remaining cost of $15,595.85 was paid for the dressed stone, installation of the arch, and building the two facades.[11]

Three years after the tunnel's completion, Solomon Roberts, the engineer who oversaw its construction, wrote a book on the portage railroad. In it he described the tunnel with these words:

> There is a tunnel through a spur of the Allegheny, at the head of inclined plane No. 1, about four miles from Johnstown near which the Conemaugh makes a bend of two miles and a half. This tunnel is 901 feet long, and 20 feet wide by 19 feet high within the arch. It is arched for 150 feet in length at each end, and the entrances are finished off with ornamental facades of cut stone. The whole cost of the tunnel, including arching, was $37,498.85 cts.[12]

The Appleton Brothers contract for building section seven did not include the railroad track. At first a single track was constructed on the line. The contractor for the tunnel track was Riddle and Sweats. By the spring of 1835 a second track had been laid. The rails consisted of wooden stringers topped with iron straps which were laid with a four-foot nine inch gauge. At first the cars were pulled through the tunnel by horse, but in 1836 locomotives replaced the animal power. This situation produced a fear that the smoke and steam from the engine produced unhealthy air in the tunnel. To calm the fright, Charles DeHass, then principal engineer, produced a report on January 14, 1837 in which he assured that the air was pure and no evil effect would come from it.[13]

During the period from the time the portage railroad opened in April 1834 until the Staple Bend Tunnel was abandoned in December 1852, repair records do not indicate any work was needed on it. In 1837 a lead pipe was laid through the tunnel to carry water from the east side to the canal on the west.[14]

Although proposals were made in the 1830s and 1840s to develop a planeless portage railroad, nothing came of these overtures until 1850. On May 10 of that year, the state legislature passed an act to make a survey for a planeless portage. Construction on this new portage railroad began in June 1851. Work progressed so quickly that by the end of 1852 the first three planes on the old portage were no longer needed. Staple Bend Tunnel, which fell within this area of the old portage railroad, was abandoned. On July 1,

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11. Work Estimates for Section 7 by J. and E. Appleton, August 1832-July 1833, Check Rolls, Work Estimates, Receipts, and Miscellaneous Accounts, Boxes 4-6, Allegheny Portage Railroad, Engineers Accounts, Estimates, Work Receipts, RG 17; Solomon W. Roberts, *An Account of the Portage Railroad over the Allegheny Mountains in Pennsylvania* (Philadelphia: Nathan Kite, 1836), 8.

12. Roberts, *An Account of the Portage Railroad Over the Allegheny Mountains in Pennsylvania*, 8.

13. Heydinger, "Comprehensive History of the Pennsylvania Canal System," v:19; Peregrin Prolix, *A Pleasant Peregrination through the Prettiest Parts of Pennsylvania* (Philadelphia: Crigg and Elliot, 1836), 37; Logue, "History of Old Portage Railroad;" McCullough and Leuba, *The Pennsylvania Main Line Canal*, 62.

14. Heydinger, "Comprehensive History of the Pennsylvania Canal System," V:14.

1855 the new portage line came into use and the entire route of the old portage was forsaken. In anticipation of that event, the legislature passed and the governor signed an act on May 8, 1855, which authorized the sale of the canal and old portage railroad. No bids were made to purchase this transportation system. Another act for its sale was approved on May 16, 1857. The Pennsylvania Railroad Company, which by this time had completed its line across the state, bought the property on June 25, 1857 as the only bidder. It took possession on August 1 of that year.[15]

The Pennsylvania Railroad made no use of Staple Bend Tunnel. In 1858 it removed the rails. The portage route including the tunnel became a roadway for area residents. By 1889 this use, by and large, had been discontinued. Sometime before 1889 the facade on the east portal of the tunnel was removed for building purposes (figures 1-3). As constructed, both ends of the tunnel had the same facade design. It was described as a Roman Revival style with a low relief lintel supported by Doric pilasters on each side (figures 4-9).[16]

Since no photographs exist of the tunnel's east portal with a facade, a question has arisen as to whether that entrance had a facade or not. The written evidence indicates clearly that it did. In a May 16, 1832 communique, Sylvester Welch indicated the tunnel plan called for facades at each end.[17] Solomon Roberts, the engineer who oversaw construction, wrote in a book in 1836 that "the entrances are finished off with ornamental facades of cut stone."[18] He also gave the same description in an 1837 newspaper article and in his 1882 reminiscences. An account in the Johnstown *Mountain Echo* of 1851 mentioned the portal facades. In 1907 Henry Storey wrote that the east entrance facade had been removed for building purposes, but he gave no indication of a date or the building on which the stones were used. The oldest dated photograph, taken in 1889, shows the east portal without a facade.[19]

The Pennsylvania Railroad did not own the tunnel property for any length of time after acquiring it in 1857. By 1867 it had sold a parcel of land which included about half of the area above the tunnel from its east side to Robert King. Another parcel, which included the ground above the tunnel from its west end, was purchased by the Cambria Iron Company. It used the area adjacent to the tunnel as a dump site for slag from its smelters. In the early 1920s Bethlehem Steel leased the Cambria Iron Company's property. On September 21, 1942 Bethlehem Steel purchased Cambria Iron. With this takeover, Bethlehem Steel acquired that portion of the tunnel in Cambria's ownership. In the meantime Bethlehem Steel purchased the King property and thereby gained control of the

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15. Jacobs, "The Old Juniata Canal and Portage Railroad," 169; Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad," xcv; Jenkins, *Pennsylvania: Colonial and Federal*, III:295; Davis, *A History of Blair County*, I:57.

16. Jacobs, "The Old Juniata Canal and Portage Railroad," 169; Henry Wilson Storey, *History of Cambria County*, vol. I (N.Y.: Lewis Publishing Co., 1907), 361; Johnson, Giles, and Michaels, "Johnstown and the Pennsylvania Canal," 220.

17. Sylvester Welch to James Clarke, President of the Board of Canal Commissioners of Pennsylvania, May 16, 1832.

18. Roberts, *An Account of the Portage Railroad Over the Allegheny Mountains in Pennsylvania*, 8.

19. Hollidaysburg (Pennsylvania) *Register*, January 18, 1837; Solomon W. Roberts, "Reminiscences of the First Railroad Over the Allegheny Mountains," *Pennsylvania Magazine of History and Biography* 2 (1878), 376; Johnstown (Pennsylvania) *Mountain Echo*, September 30, 1851; Storey, *History of Cambria County*, I:361.

entire tunnel. Staple Bend Tunnel is still in the possession of the Bethlehem Steel Corporation.[20]

Aside from general deterioration since its abandonment in 1852 and the loss of the facade from the east portal, Staple Bend Tunnel has sustained other changes. Around the turn of the century the American Pipe Line Company ran a water pipe through the tunnel. To protect the pipe, it sealed each entrance with a concrete wall (figures 2-3, 10-12). A small doorway was constructed in the center of each wall which contained a wooden header and frame. A wooden door with slating (figures 2 and 10) prevented the public from entering the tunnel. In 1951 the Bethlehem Steel Corporation laid its own water pipe system through the tunnel. At the same time it removed the upper portion of the concrete walls, which had been placed in the entrances at the turn of the century, and cut a larger doorway area. The wooden doors were replaced with larger, double metal doors which have been welded shut. Concrete blocks were used to replace the concrete removed from the upper space below the portal arches (figures 13 and 14). Closing the tunnel has helped to protect its interior. As a result, the dressed stone arch in each end remains.[21]

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20. *Atlas of Cambria County, Pennsylvania* (Philadelphia: Atlas Publishing Co., 1867); *Atlas of Cambria County, Pennsylvania* (Philadelphia: Atlas Publishing Co., 1890); information gathered at the Cambria County Courthouse, Ebensburg, Pennsylvania. Unfortunately, incorrect information filed in the Cambria County Courthouse on property ownership made it impossible to have exact dates for land purchases.

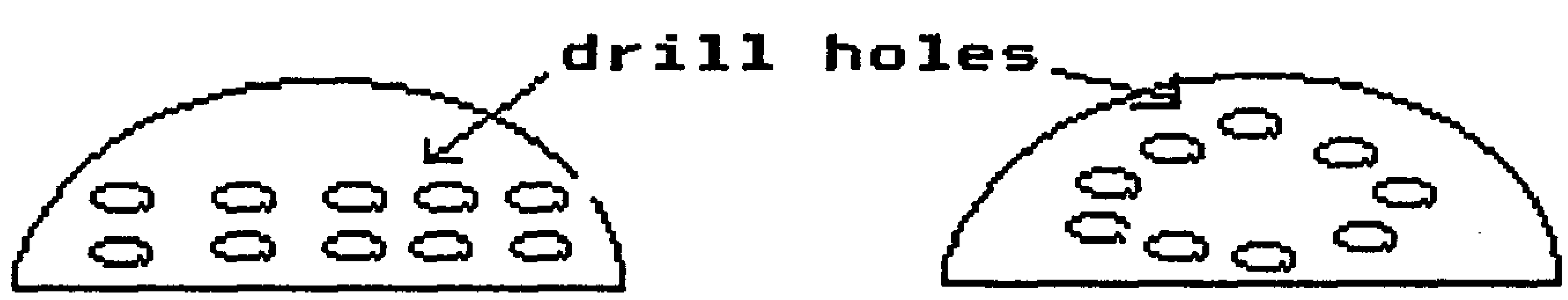
21. Information obtained from the rear of an Ira Stouffer photograph taken ca. 1910 which is located in the Pennsylvania State Archives, Harrisburg, Pennsylvania; *Tribune-Democrat* (Johnstown, Pennsylvania), February 2, 1975.

CHAPTER III

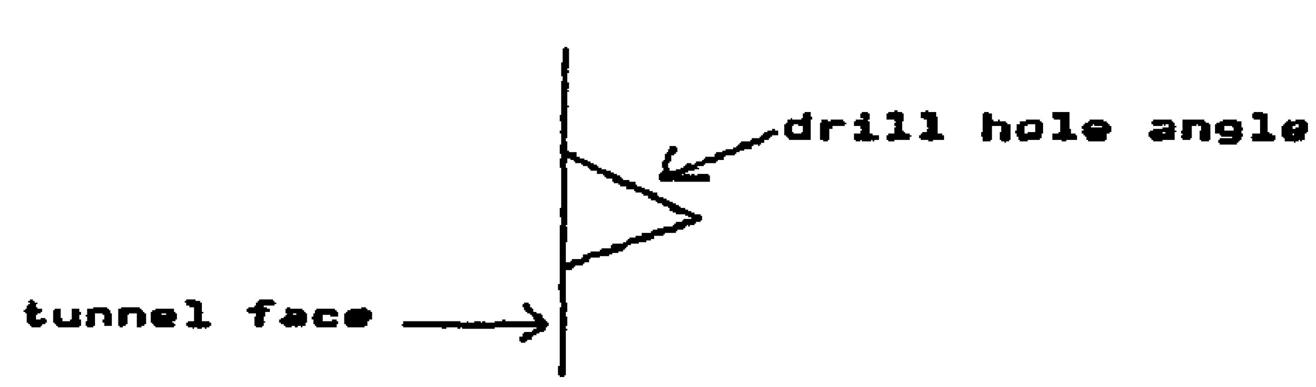
III. TUNNEL CONSTRUCTION IN THE 1830S

At the time Staple Bend Tunnel was constructed, tunnel driving was in its infancy in the United States. Although it was the first railroad tunnel in the country, two other tunnels had preceded it. Both of these earlier structures were canal tunnels. The first one, 820 feet long, was dug for the Schuylkill Canal at Auburn, Pennsylvania in 1820-21. The second tunnel, 720 feet long, was on the Union Canal near Lebanon, Pennsylvania. It was built in 1827. Without a skilled tunnel construction corps, the contractors had to rely on miners for their workforce. The skilled men who did the drilling and set the powder charges would have been Welsh immigrants, for individuals of this nationality made up the skilled mining force at the time. The common laborers who removed the muck, as the blasted rock was called, would have been Irish immigrants. Men of this nationality comprised the preponderance of the area's unskilled workers in that period.

In the 1830s tunnel construction was a simple, but laborious process. Small tunnels, such as Staple Bend which had a dimension of twenty feet wide and nineteen feet high inside the arch, were always driven full face. Before beginning to drill holes in the face, the man in charge of blasting would study the face to ascertain where to place the holes. Advantage was taken of all irregularities and joints as a means to eliminate or reduce the number of holes. The hole locations were usually placed in the following manner:



The holes were driven at an angle.[1]



All holes were drilled by hand with either a single-jacked or double-jacked method. A single jack was a hammer weighing about four pounds. It was swung with one hand while the drill was held by the other hand. The double jack was a six to eight-pound sledge held with both hands. Generally, two men struck with double jacks, while a third

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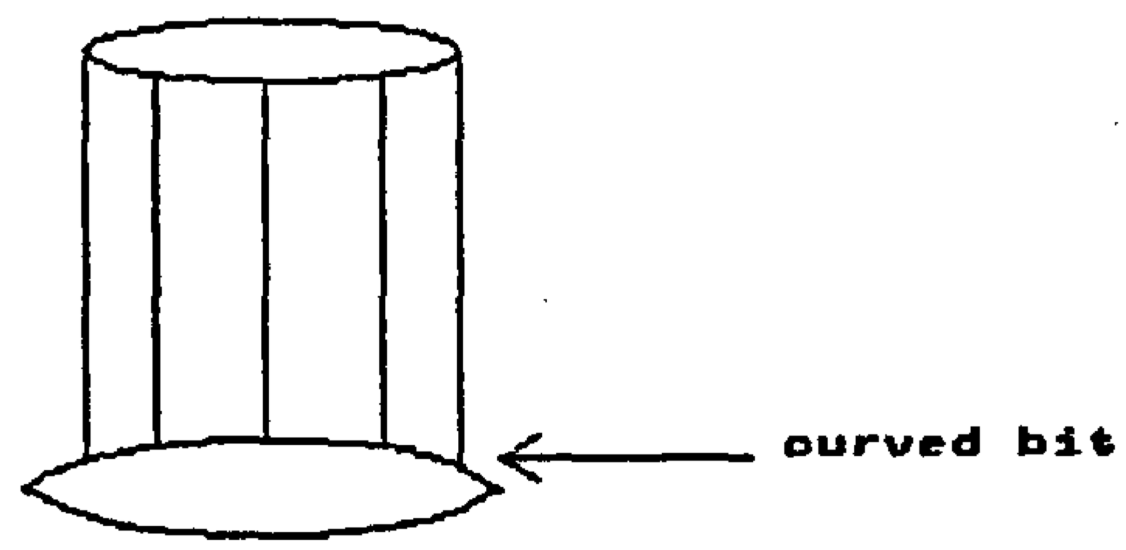
1. Harold W. Richardson and Robert S. Mayo, *Practical Tunnel Driving* (N.Y.: McGraw-Hill Book Co., 1941), 300, 333; Drinker, *Tunneling, Explosive Compounds, and Rock Drills,* 108.

man held the drill and turned it a quarter-turn after each blow. Theoretically, the drill was turned on a center in the middle of the hole. The successive cuts crossed each other and the hole was broken a little wider in diameter than the drill diameter. A curved bit on the end of the drill (as shown) had, for centuries, proved best for two reasons.



Curved bits gave the most uniform wear. In addition, drills were not usually held straight and the hammer blow was usually not directly on center. As a result, a curved drill bit was found to transfer an off-center hammer blow more directly to the center of the drill bit. Thus, more energy from the force of the blow went into drilling the hole. Since metallurgy had not reached modern standards in the 1830s, the softer drill bits of those days required frequent sharpening. Consequently, a temporary blacksmith shop would have been located at Staple Bend Tunnel, where blacksmiths would have been kept constantly busy sharpening drill bits.[2]

Drilling was time consuming work. Holes were usually one-inch in diameter and seldom deeper than three feet. A three-man double jack team could drill about one foot of hole per hour. This depth per hour, however, varied with the density of the rock. The sandstone encountered throughout much of Staple Bend Tunnel probably allowed a team to drill an average of one foot per hour.[3]

Once the proper number of holes had been drilled, the tunnel face was ready for blasting. Each hole was charged with black powder. Staple Bend workers used an average of 200 pounds of powder per week. The powder was contained in a one-pound, paper wrapped cartridge. It was pushed to the bottom of the hole by using a wood or copper pole. A copper needle, which was a small rod, was inserted into the hole and then the hole was filled with clay and tamped with the wood or copper rod. After tamping, the copper needle was withdrawn leaving a small hole through which the fuse was introduced. Fuses of the day consisted of reeds, straws, or small round paper tubes filled with powder. In 1831 a safety fuse, the Bickford fuse, was invented in England. It comprised a cord around a thin vein of powder. The cord was covered with tar or pitch. The advantage of this fuse was its steady uniform burn. Whether this fuse was used at Staple Bend Tunnel remains unknown, but it could have been used toward the end of the digging.[4]

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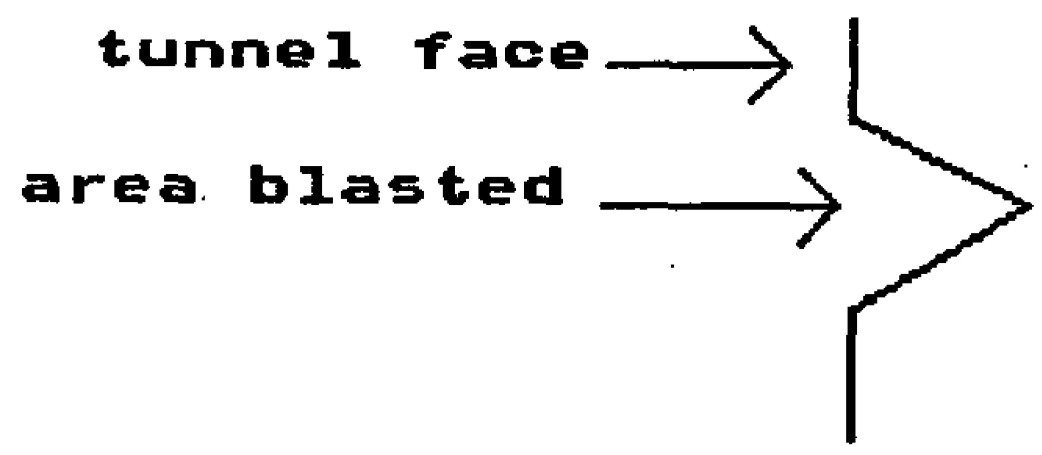
2. Drinker, *Tunneling, Explosive Compounds, and Rock Drills,* 114-16; Richardson and Mayo, *Practical Tunnel Driving,* 332-333.

3. Richardson and Mayo, *Practical Tunnel Driving,* 333.

4. Gösta E. Sandström, *Tunnels* (N.Y.: Holt, Rinehart and Winston, 1963), 282; Drinker, *Tunneling, Explosive Compounds, and Rock Drills,* 108-109; David W. Burton and John A. Davis, *Modern Tunneling* (N.Y.: John Wiley & Sons, 1914), 295.

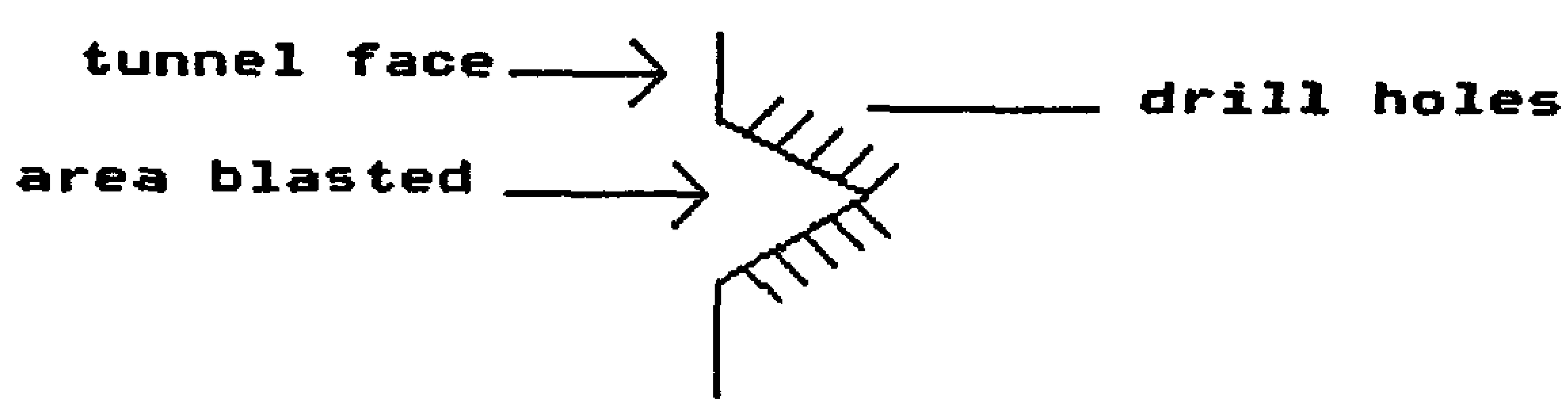
Blasts tended to be somewhat dangerous, since the fuses burned unevenly. The force of the blast would leave a cone-shaped hole in the tunnel face.



Rarely did the blast penetrate to the depth of the drill hole. The average explosion would remove rock to about eighteen inches less than the hole depth. Since the average hole was drilled to a depth of three feet, the average blast removed eighteen inches of rock. This corresponded with Sylvester Welch's report in May 1832 that eighteen inches of rock was removed from the tunnel face in a twenty-four hour period.[5]

Blasts were usually set just before meal time so that the dust could settle while the workforce ate. After the dust settled, several men entered the tunnel to carefully inspect the walls and roof before the others entered. Inspection was both visual and by using a hand hammer. Any spot which sounded hollow under a hammer blow needed investigation. Timbers were then placed in appropriate locations. Then the heading and tunnel face had to be scaled of loose rock before mucking could begin.[6]

While mucking or removal of the blasted rock occurred, the skilled labor returned to drilling holes in the cone-shaped area so that the tunnel face could be blasted flush. This condition was accomplished by drilling holes in the following manner:



Muckers had the most exhausting job in tunnel driving. This work was accomplished by hand labor. A twenty-foot wide tunnel like Staple Bend could accommodate no more than eight men shoveling at one time. These men shoveled the rock into a cart pulled by a horse. At the same time two to four men were employed with a pick to pull down the rock pile in front of the shovelers. These laborers periodically alternated with the shovelers to

5. Richardson and Mayo, *Practical Tunnel Driving,*, 333.

6. Ibid., 65-66.

give them relief from the fatiguing work. The amount of rock a man could shovel was usually figured at one-half to two-thirds cubic yard per hour.[7]

The greatest danger in tunnel driving came from natural causes and the failure to realize what could happen when the rock structure was disturbed. The soft rock encountered in one area of Staple Bend Tunnel undoubtedly gave safety concerns; however, no reports or newspaper articles have surfaced about any deaths or maimings that occurred during the tunnel's construction. The soft rock area was undoubtedly covered by the tunnel arch. As a result, any future repair work involving the arch should be done with care in anticipation of a soft rock area above the arch.

7. Richardson and Mayo, *Practical Tunnel Driving,* 90; Burton and Davis, *Modern Tunneling,* 261.

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ILLUSTRATIONS

Figure 1: Staple Bend Tunnel East Portal, July 13, 1889
Courtesy of the Johnstown Flood Museum

This photograph shows that the portal facade had been removed before 1889. Henry Wilson Storey in his history of Cambria County reported that the facade had been removed for construction elsewhere.

Figure 2: Staple Bend Tunnel East Portal, ca. 1910

MG 327, Ira J. Stouffer Collection, Pennsylvania State Archives, Harrisburg, Pennsylvania

This photograph shows the concrete wall with wooden, slated door placed across the tunnel entrance by the American Pipe Line Company around the turn of the century.


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TUNNEL
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Figure 3: Staple Bend Tunnel East Portal, ca. 1910
MG 286, Pennsylvania State Archives, Harrisburg, Pennsylvania

Taken during the winter, this photograph reveals the same features as the previous figure.

Figure 4: Staple Bend Tunnel West Portal, ca. 1895

Courtesy of the Smithsonian Institution, Washington, D.C.

This photograph reveals the Roman Revival style facade with its low relief lintel supported by Doric pilasters. One can also see the eighteen-inch thick dressed stone of the arch or lining. The tunnel was arched for 150 feet from each end.

Figure 5: Staple Bend Tunnel West Portal, ca. 1890
Courtesy of the Smithsonian Institution, Washington, D.C.

This photograph is a frontal picture of the west facade before the portal was sealed with a concrete wall. The top course of facade stone has sustained less damage than revealed in the previous figures.

Figure 6: Staple Bend Tunnel West Portal, ca. 1890

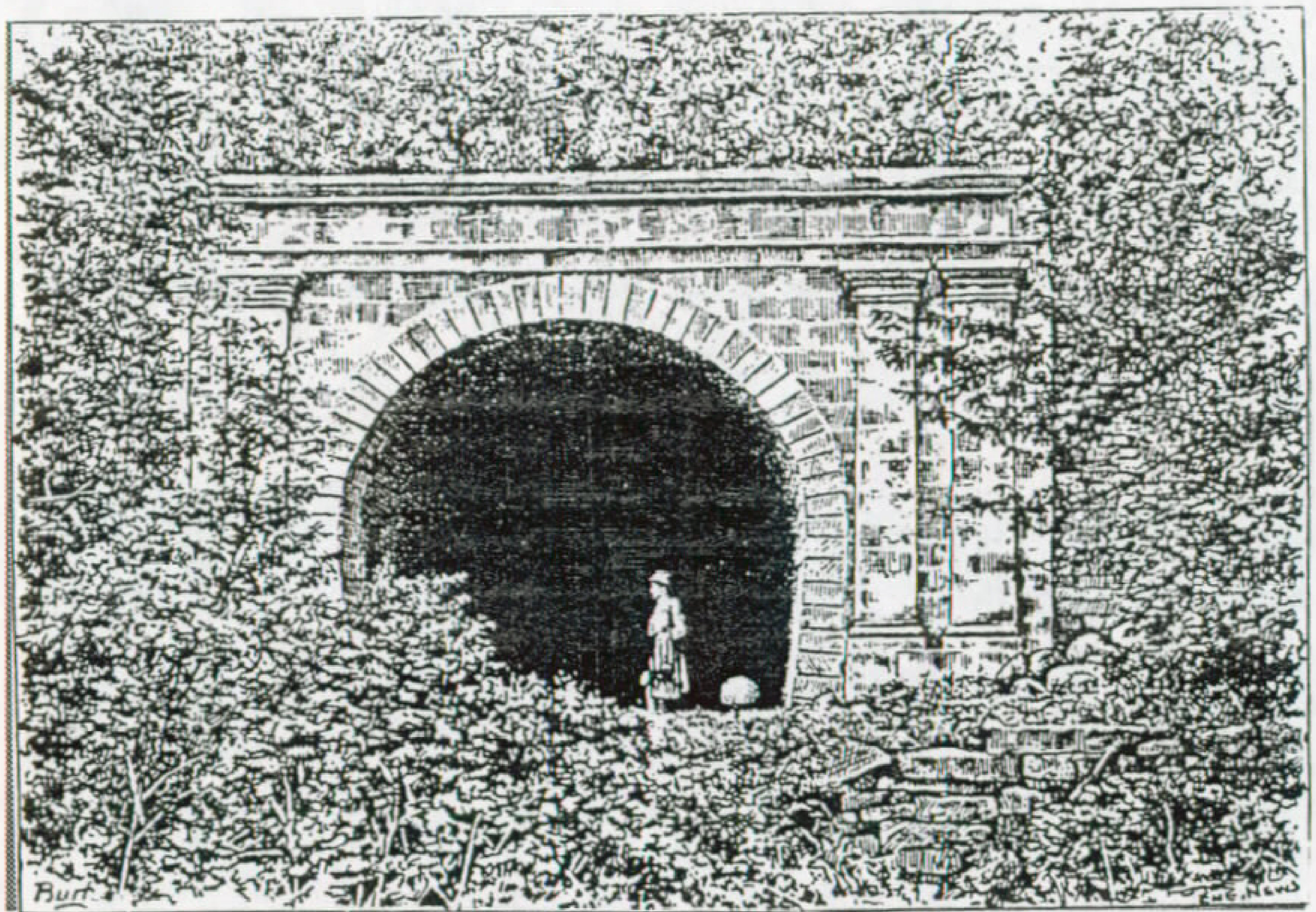
Courtesy of the Smithsonian Institution, Washington, D.C.

Another frontal photograph which shows what is probably the rock foundation of the engine house a short distance in front of the tunnel entrance.

Figure 7: Staple Bend Tunnel West Portal, ca. 1895

MG 286, Pennsylvania Railroad Collection, Pennsylvania State Archives, Harrisburg, Pennsylvania


M.E. 3533



THE OLDEST RAILROAD TUNNEL IN AMERICA.

Portage Railroad. Constructed 1832, abandoned 1852. View of West Portal in 1892.

Figure 8: In George H. Burgess and Miles C. Kenney, *Centennial History of the Pennsylvania Railroad Company.*

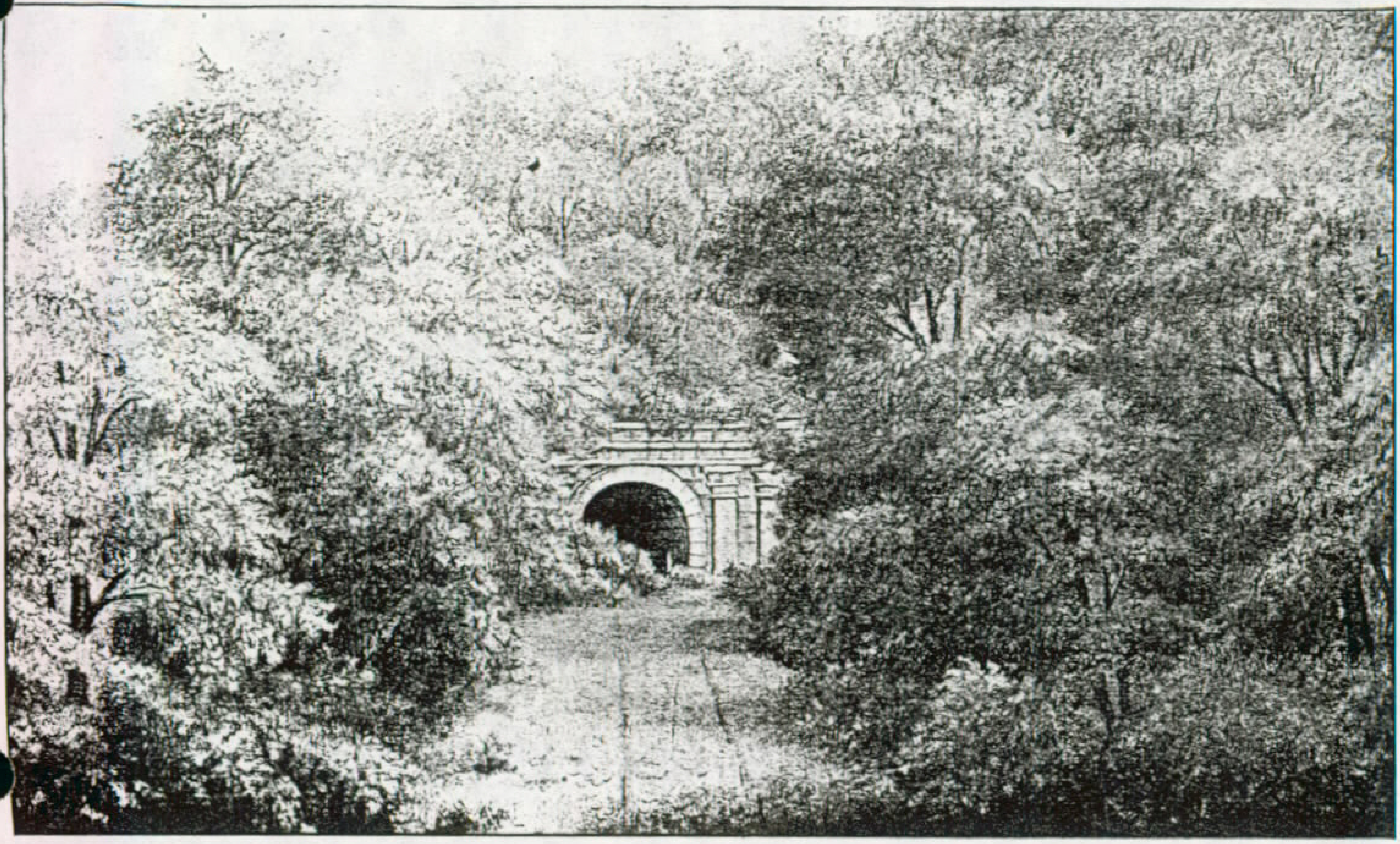


Figure 9: View of the West portal in 1896

In William B. Wilson, "The Evolution, Decadence and Abandonment of the Allegheny Portage Railroad."

Figure 10: Staple Bend Tunnel West Portal, ca. 1910

MG 327, Ira J. Stouffer Collection, Pennsylvania State Archives, Harrisburg, Pennsylvania

This photograph shows the concrete wall with wooden, slated door placed across the tunnel entrance by the American Pipe Line Company around the turn of the century.


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Figure 11: Staple Bend Tunnel West Portal, ca. 1920
Courtesy of the Smithsonian Institution, Washington, D.C.

This photograph reveals the further ravages of time and vandals.

Figure 12: Staple Bend Tunnel West Portal, ca. 1920

MG 286, Pennsylvania Railroad Collection, Pennsylvania State Archives, Harrisburg, Pennsylvania

This photograph presents the same appearance as the previous figure. The slated door has been removed from the entrance.

Tunnels - Staple Bend - West Portal - Allaghegheny Portage

Figure 13: Staple Bend Tunnel West Portal, October 1988

In this photograph one can see the concrete blocks used to replace the concrete wall in the upper portion of the portal in 1951. The wooden header and frame of the doorway were removed at the same time and replaced by the lager, double metal doors shown in this picture.

Figure 14: Staple Bend Tunnel East Portal, October 1988

Heavy overgrowth obstructs the view of the east entrance, but this portal sustained the same changes in 1951 as noted in the previous figure of the west portal.


DEER
Buch

GEI Consultants, Inc.

STAPLE BEND TUNNEL
JOHNSTOWN, PENNSYLVANIA

Submitted to

Sellards & Grigg, Inc.
Lakewood, Colorado 80228

1021 Main Street
Winchester, MA 01890-1943
617-721-4000

Project 90259
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Project 90259

Alton P. Davis, Jr., P.E.
Project Manager

frame during which the sediments forming these rocks were deposited, i.e., about 250-300 million years ago.

Tunnel Stability

The field effort was performed to assess the long-term stability of Staple Bend Tunnel and to evaluate what measures could be taken to increase tunnel stability if required. An evaluation of the tunnel stability requires knowledge of: 1) the condition of the various bedrock types present and 2) orientation of discontinuities (planes of weakness) which largely control rock block stability.

The tunnel alignment is coincident with the axis of a gently folded anticline such that the rock strata bedding planes arch downward into and away from both tunnel walls. The massive "upper sandstone" bedrock exposed in the crown of the tunnel (Subsection 2.3) forms a natural arch over the tunnel. The configuration of this rock structure relative to the tunnel opening provides a generally stable condition. Rock above and below bedding planes which dip downward into the walls and away from the tunnel opening are not susceptible to slippage. In addition, arching stresses which form in the roof rock of the tunnel tend to strengthen the rock and increase stability by inducing compressive stresses in the lower bedrock strata.

The orientations of faults and major joint sets exposed in the tunnel were observed. In general, these features cross the tunnel alignment with many striking nearly perpendicular to the axis of the tunnel. Due to the widely spaced nature of these features and their orientations, the intersections of these planar weakness with bedding planes or with each other, are not likely to result in a large number of unstable blocks or wedges of rock. Nevertheless, during any remedial work in the tunnel, close inspection of all potentially adversely bounded rock blocks or wedges should be made to define any bolting or stabilization requirements on a site-by-site basis.

West Portal Facade

The west portal facade has experienced some displacement and distress, particularly along the top cornice. Tree roots and freeze/thaw cycles have displaced many of the top masonry courses. Some of the displaced blocks should be removed, the trees and roots eliminated, and the blocks reset to restore the facade and prevent future distress.

The slope above the portal is an earth backfill placed over the masonry liner to shed rainfall and keep the tunnel dry. Heavy tree growth, failure of dry laid masonry retaining walls adjacent to the portal facade and erosion have damaged the earth backfill. The dry masonry walls should be restored; the trees, stumps, and roots removed; and the earth backfill restored.

The west masonry-lined portion of the tunnel is in good condition. The masonry lining to be founded on the original tunnel invert bedrock. The masonry consists of dressed stones tapered to fit the arch shape. Evidence of mortar between masonry blocks was observed in many areas. However, in some areas, particularly in the crown, the mortar appears to have been lost due to long-term leaching by ground water seepage.

At two locations on the west masonry lining, individual blocks in the crown have fallen out or partially displaced due to loss of confining mortar. At Sta. 0+58, a crown block appears to have split on a natural defect with the upper half remaining in place and the lower half fallen out. At Sta. 1+03, a keystone block is missing. It will be necessary to replace these masonry blocks and to repoint the masonry liner for safety against future block falls prior to opening the tunnel to public access. The mortar used in the repointing will need to be sensitive to the type of mortar used originally, yet be compatible with the masonry blocks.

Bedrock Tunnel Section

Some of the weaker rock strata exposed in the tunnel walls, particularly siltstone stratum and the rusty brown portion of the lower sandstone stratum have been severely fractured in place by what appears to be ancient, near horizontal shearing and thrusting between more competent underlying and overlying rock strata. Many of these sheared (fractured) areas have been eroded and undermined by active spalling for several feet in form the original tunnel wall surface. The spalling observed in the undermined areas will not influence the overall stability of the tunnel, particularly since the air temperature in the tunnel has equilibrated due to closure of the tunnel portals. However, the spalling and erosion is expected to continue and if left unchecked will eventually jeopardize the stability of any overhanging rock strata. Activity could accelerate if the portal closures were eliminated, and freeze/thaw cycles resumed in the tunnel. In those areas where overhangs exceed about 3 feet horizontally into the wall, stabilization should be provided to prevent future rockfalls.

The east masonry-lined section is in good condition. Only limited repointing of the east masonry lining will be required. The mortar used for repointing must be sensitive to the type of mortar originally used, yet be compatible with the masonry blocks.

Concrete-Lined Section

The masonry lining in the eastern 50 feet of the tunnel has been reinforced with a concrete supplemental liner. The concrete lining is in excellent condition with no remedial work required.

East Portal Facade

The east portal was originally constructed with the same facade structure as the west portal. Reference 3 indicates that between 1896 and 1910, the east portal facade was removed to supply building stone.

Before general public access to the tunnel is permitted, the area above the east portal should be stabilized. All trees should be cleared and stumps removed. Assuming the original portal facade will not be replicated, all loose earth and rock backfill should be removed from above the portal, new dry stone masonry or concrete retaining walls constructed and new earth backfill placed to restore safety against debris falling from above the portal. Particular care must be taken to stabilize the area to the south of the portal.

Engineer's Cost Estimates

Staple Bend Tunnel has been found to be in relatively good condition for a 160-year-old facility. Remedial work required to be performed prior to allowing general public access to the tunnel and an engineer's cost estimate (Table 1) for the remedial work required inside the tunnel only are provided in this report. Costs of remedial work on the west portal facade, stabilization of slopes above the east and west portals, and other exterior work are addressed by Sellards & Grigg ([Ref. 2].

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1. INTRODUCTION

1.1 Purpose

Staple Bend Tunnel is located in Cambria County, northwest of Johnstown, Pennsylvania (Fig. 1) and is the first railroad tunnel constructed in the United States. The tunnel is a major feature of the Allegheny Portage Railroad which was constructed between 1831 and 1834. The portage railroad used a series of inclines and levels to transport loaded canal barges from canal slips at Hollidaysbury over the Allegheny Mountains to the canal slips in Johnstown, thus linking the canal systems from Philadelphia to Pittsburgh, Pennsylvania.

This report presents observations made between August 20 and 24, 1990 to assess the structural integrity of the tunnel. A previous familiarization site visit was conducted on February 15, 1990 [Ref. 1]. Recommendations for safety improvements to the tunnel and engineer's cost estimates for these safety improvements are provided.

1.2 Scope of Work

Our scope of work included the following tasks as part of Sellards & Grigg, Inc.'s Historic Structure Report for Staple Bend Tunnel:

- Provide field geologist to prepare profiles of the exposed bedrock in the tunnel including geologic structure, bedding strike and dip, and bedrock strata.

- Excavate and log test pits to investigate the tunnel invert, locate the Bethlehem Steel Company water supply line in the tunnel invert, observe foundation conditions for the tunnel masonry liners and portal facades, and observe backfill over the east portal masonry liner.

- Assess code requirements to identify safety regulations related to public access into the tunnel.

- Provide a report presenting our observations and recommendations.

- Prepare a Class B level cost estimate for work required to stabilize the interior of the tunnel.

- GEI project manager to visit the site during the field work and attend a 50% level review meeting in Denver. GEI Denver staff liaison to attend 95% level review meeting in Denver.

1.3 GEI Project Staff

The following key GEI staff worked on the project.

Alton P. Davis Jr., P.E.	Project Manager
William E. Pitt Jr.	Senior Geologist
John W. France	Denver Liaison
Ronald C. Hirschfeld, Ph.D., P.E.	Principal-in-Charge

1.4 Authorization

This work was authorized by Sellards & Grigg, Inc. Purchase Order No. 90783-31 dated June 29, 1990.

1.5 Project Datum

Project surveys were conducted by EADS Group. The project datum is National Geodetic Vertical Datum (NGVD) Mean Sea Level (1929). The existing tunnel invert is approximately El. 1424.

faults, shear zones, joints and bedding plane weaknesses which largely control the local stability of the tunnel walls and crown. The observations of the field geologic mapping are presented in Figs. 4 through 10.

Geologic mapping was limited to the areas of exposed bedrock between Stas. 1+50 and 7+50. Figures 4 through 10 each present a profile of both the north and south walls of a 100 feet length of the tunnel. The north wall is shown on the top of the figure as viewed from inside the tunnel, while the south wall is shown on the bottom of the figure as viewed by an observer looking out into the tunnel. This method permits the direct comparison of geologic features across the tunnel.

The strip in the middle of each figure is a record of strike and dip measurements of key geologic features. A legend for the strike and dip measurements is shown in Fig. 3.

2.3 Tunnel Geology

The bedrock structure exposed in the crown and sidewalls of the tunnel consists of a series of sedimentary strata which are slightly folded upward to form a gently plunging anticline structure. The axis of the anticline roughly parallels the tunnel axis and dips slightly (plunges) toward the east portal. The rock strata comprising the anticline consist of interbedded sandstone, siltstone, shale, and coal. These strata have been disrupted by: 1) several low angle normal faults which cross perpendicular to the tunnel alignment and 2) nearly horizontal shearing and thrusting along some of the weaker rock strata.

The strata exposed in the tunnel consisted of several rock types which were continuously or intermittently exposed along the walls and crown of the tunnel. A brief description of each of these rock types (listed from highest to lowest elevation) is presented below.

Upper Sandstone - The most prevalent rock strata exposed in the tunnel is a brown fine-grained massive to thin-bedded sandstone. This rock is exposed in the upper ¼ to ½ of the tunnel and forms the crown of the tunnel throughout its entire length. In several areas of the tunnel the base of the unit contains thin, black shale interbeds. In general, this unit is hard and competent with only occasional occurrences of joints other than bedding plane joints. Numerous fossilized plants were observed in the upper sandstone as discussed in Section 4.

Carbonaceous Shale - The base of the upper sandstone strata is marked by a generally thin, intermittently exposed black carbonaceous shale bed. In total, this bed was observed over one half of the tunnel length. However, it is missing in places, particularly in the east end of the tunnel due to either displacement by horizontal shearing, faulting and/or lensing. The carbonaceous shale is characteristically fissile.

Siltstone - Beneath the upper sandstone and carbonaceous shale strata is a nearly continuous massive gray siltstone strata which varies in thickness from a few feet near Sta. 1+50 (Fig. 4) to greater than 10 feet near Sta. 7+50 (Fig. 10). Between Stas. 5+50 and 7+50, the "upper sandstone" grades laterally into this gray siltstone stratum. Between Stas. 1+50 and 4+50 (Figs. 4 to 7), this brittle rock is severely fractured in place as a result of what appears to be horizontal shearing and faulting. Where the fracturing is severe, the rock pieces and chips comprising the siltstone strata commonly exhibit polished or striated slickensided surfaces, and in places the strata is distorted and/or crenelated.

Coal - Within the thicker portions of the siltstone stratum between Stas. 5+50 and 7+50 (Figs. 8 to 10), are thin (0.4 to about 0.8 feet thick), bituminous coal seams. The coal is sheared and displaced by two low-angle normal faults near Sta. 6+50 (Fig. 9). West of the faults there is only one coal seam, while east of the fault there are two coal seams. This suggests that there is probably a significant strike-slip (lateral) component of movement along the faults causing one of the coal seams to appear pinched out on the western down thrust side of the fault.

Lower Sandstone - A lower generally massive sandstone stratum was present throughout the tunnel invert except between approximately Stas. 5+00 to 7+50 (Figs. 8 to 10) where it dips beneath the invert of the tunnel. The maximum exposure of this stratum is about 14 feet thick and is comprised of an upper competent massive gray to black sandstone underlain by rusty brown severely fractured sandstone. The portion of the tunnel walls comprised of the lower rusty brown sandstone are severely fractured and weathered between approximately Stas. 1+50 and 2+75.

At Sta. 4+00 (Fig. 6), a major normal fault truncates the massive dark gray to black sandstone strata and the more fractured lower brown sandstone unit reappears on the upthrown (east) side of the fault. Due to the moderately fractured nature of the rusty brown sandstone extending from Sta. 4+00 to Sta. 4+50, the tunnel walls are significantly undermined up to a height of about 9 or 10 feet above tunnel invert and into the tunnel walls up to about 4 to 6 feet. Appendix B presents cross sections and a centerline profile of the tunnel prepared by EADS Group. Examples of the overhang caused by weathering of the rusty brown sandstone can be seen in cross sections at Stas. 2+25, 4+37, and 6+15 (Appendix B).

3. TEST PIT PROGRAM

During the period August 21 through August 24, 1990, a total of six test pits were hand dug both within and outside of the tunnel. The test pits were excavated by personnel from Charles J. Merlo, Inc. of Mineral Point, Pennsylvania, and observed and logged by a GEI engineering geologist. The locations of the test pits are shown in Fig. 2. GEI's test pit logs are presented in Appendix A.

Test Pits 1 and 3 were performed at the base of the masonry arches at the west and east portal areas at Stas. 0+59 and 7+46, respectively. These test pits were performed to investigate the foundation configuration at the bottom of the arches and to investigate the bearing characteristics of the bedrock supporting the arches.

Test Pit 2 was performed across the full width of the tunnel invert at Sta. 3+00. This test pit documented the thickness and type of fill placed over the tunnel bedrock invert, the depth to invert bedrock, and the location and depth of a 48-inch-diameter concrete water main installed along the invert of the tunnel by Bethlehem Steel Company in the 1940s.

Test Pit 4 was performed at the base of the intersection of the concrete-lined portion of the eastern portal area with the original masonry lining. The purpose was to investigate the footing foundation configuration for both the concrete liner and adjacent masonry arch and to investigate the depth and bearing characteristics of the bedrock supporting the arch and liner.

Test Pit 5 was performed at the south side of the west portal facade to investigate the depth and configuration of the foundation and bearing characteristics of the bedrock supporting the facade.

Test Pit 6 was performed on the north side of the east portal to remove the soil fill cover and examine the condition of the original masonry arch lining. This area of the arch had experienced lateral displacement of the arch axis to the north of its original position.

Observations made in the test pits are summarized in Table A1, Appendix A.

5. TUNNEL STABILITY EVALUATION

5.1 General

The field effort was performed to assess the long-term stability of Staple Bend Tunnel and to evaluate what measures could be taken to increase tunnel stability if required. An evaluation of the tunnel stability requires knowledge of: 1) the condition of the various bedrock types present and 2) orientation of discontinuities (planes of weakness) which largely control rock block stability. Large scale slides and rockfalls can take place when discontinuities such as faults or bedding plane joints intersect to form unrestrained blocks or wedges. Smaller rockfalls resulting from spalling, toppling, or crown slabbing are dependent on the degree of fracturing, jointing, and bedding plane thickness of the rock strata, slides and rockfalls are usually caused or accelerated by surface weathering, frost action, root wedging, and water pressure in discontinuities in the rock.

5.2 Significance of Rock Structure and Discontinuities on Tunnel Stability

The tunnel alignment is coincident with the axis of a gently folded anticline such that the rock strata bedding planes arch downward into and away from both tunnel walls. The massive "upper sandstone" bedrock exposed in the crown of the tunnel (Subsection 2.3) forms a natural arch over the tunnel. The general configuration of this rock structure relative to the tunnel opening provides a generally stable condition. Rock above and below bedding planes which dip downward into the walls and away from the tunnel opening are not susceptible to slippage. In addition, arching stresses which form in the roof rock of the tunnel tend to strengthen the rock and increase stability by inducing compressive stresses in the lower bedrock strata.

The orientations of faults and major joint sets exposed in the tunnel were observed to evaluate the potential for these features to contribute to tunnel instability. In general, these features cross the tunnel alignment with many striking nearly perpendicular to the axis of the tunnel. Due to the widely spaced nature of these features and their orientations, the intersections of these planar weakness with bedding planes or with each other, are not likely to result in a large number of unstable blocks or wedges of rock. Nevertheless, during any remedial work in the tunnel, close inspection of all potentially adversely bounded rock blocks or wedges should be made to define any bolting or stabilization requirements on a site-by-site basis.

5.3 West Portal Facade

The west portal facade has experienced some displacement and distress, particularly along the top cornice. Tree roots and freeze/thaw cycles have displaced many of the top masonry courses. Some of the displaced blocks should be removed, the trees and roots eliminated, and the blocks reset to restore the facade and prevent future distress. During this work, evidence of original construction methods should be recorded.

Test Pit 5 (Appendix A) showed that the portal facade is founded on competent sandstone. Observations indicate that the sandstone was carefully leveled prior to construction to form a true base for the facade masonry. The facade foundation is in very good condition.

The slope above the portal is an earth backfill placed over the masonry liner to shed rainfall and keep the tunnel dry. Heavy tree growth, failure of dry laid masonry retaining walls adjacent to the portal facade and erosion have damaged the earth backfill. The dry masonry walls should be restored; the trees, stumps, and roots removed; and the earth backfill restored.

5.4 West Masonry-Lined Section

Observations made during the preliminary site visit on February 15, 1990, [Ref. 1] and confirmed during the August 21 to 24, 1990, site investigations show that the west masonry-lined portion of the tunnel is in good condition. Test Pit 1 (Appendix A) showed the masonry lining to be founded on the original tunnel invert bedrock. The masonry consists of dressed stones tapered to fit the arch shape. Evidence of mortar between masonry blocks was observed in many areas. However, in some areas, particularly in the crown, the mortar appears to have been lost due to long-term leaching by ground water seepage. During original construction, the annular space between the masonry arch and the bedrock tunnel opening was filled with hand placed rock rubble to support the bedrock and distribute the load of any loose bedrock blocks more evenly onto the masonry lining.

At two locations on the west masonry lining (Stas. 0+58 and 1+03), individual blocks in the crown have fallen out or partially displaced due to loss of confining mortar. At Sta. 0+58, a crown block appears to have split on a natural defect with the upper half remaining in place and the lower half fallen out. At Sta. 1+03, a keystone block is missing, and the overlying rubble backfill can be observed. It will be necessary to repoint the masonry liner for safety against future block falls prior to opening the tunnel to public access. The mortar used in the repointing will need to be sensitive to the type of mortar used originally, yet be compatible with the masonry blocks.

From the west portal facade to approximately Sta. 0+30, the west masonry arch is formed by uniform dimension stone blocks [Ref. 1]. Between Stas. 0+30 and 0+40, the masonry arch crown transitions from uniform to variable dimension blocks which are used throughout the remainder of the masonry-lined portion of the tunnel.

It should be noted that the outer section of the tunnel masonry lining is a transition between the actual bedrock tunnel and the portal facade. The masonry lining was intended to support the weaker bedrock near the portal and was extended beyond the bedrock portal face to provide safety against falling rock or other debris that might otherwise have landed on the railroad tracks. It is speculated that the transition between Stas. 0+30 and 0+40 occurs at the original rock portal face (i.e., the actual start of the bedrock tunnel). Outside of the original rock portal, the masonry arch could be constructed by heavy lifting equipment capable of placing blocks weighing up to 500 pounds each. Inside the tunnel, however, the keystone and upper crown blocks would have to be placed by manpower on top of a timber frame and smaller stones were required. The smaller keystones appear to be about 150 to 200 pounds in weight.

5.5 Bedrock Tunnel Section

In general, the tunnel crown appears to be in good condition. Nevertheless, the crown of the tunnel must be closely inspected to locate any unstable rock blocks prior to permitting public access. Unstable blocks should be removed or stabilized with rock dowels.

Some of the weaker rock strata exposed in the tunnel walls, particularly the siltstone stratum and the rusty brown portion of the lower sandstone stratum have been severely fractured in place by what appears to be ancient, near horizontal shearing and thrusting between more competent underlying and overlying rock strata. Many of these sheared (fractured) areas have been eroded and undermined by active spalling for several feet in form the original tunnel wall surface (Section 2). This spalling has most likely been caused by freeze/thaw expansion and wet/dry cycles acting on the fracture surfaces, particularly when the tunnel was open at both ends and subjected to seasonal variations in air temperature. Ground water infiltration into the tunnel may also have contributed to the spalling. The spalling observed in the undermined areas will not influence the overall stability of the tunnel, particularly since the air temperature in the tunnel has equilibrated due to closure of the tunnel portals. However, the spalling and erosion is expected to continue and if left unchecked will eventually jeopardize the stability of any overhanging rock strata. Activity could accelerate if the portal closures were eliminated, and freeze/thaw cycles resumed in the tunnel.

The overhangs generally occur under the more resistant strata. As weathered material falls (spalls) away, it piles up along the lower wall thus protecting the lower exposure against further deterioration. Generally the fallen material forms slopes of about 45 degrees, and the depths of overhangs are generally limited by the rate of weathering and the height of the resistant strata above the invert. In those areas where overhangs exceed about 3 feet horizontally into the wall, stabilization should be provided to prevent future rockfalls.

Test Pit 2 (Appendix A) was excavated at Sta. 3+00 to investigate the tunnel bedrock invert and to locate the Bethlehem Steel Company water supply line. The excavation exposed competent sandstone bedrock at a depth of about 2.6 feet (El. 1426 ±). The water supply line was confirmed as a 48-inch-outside-diameter concrete pipe located approximately in the center of the tunnel. The test pit did not expose the invert of the pipe.

5.6 East Masonry-Lined Section

The east masonry-lined section is in good condition. Test Pit 3 (Appendix A) showed the masonry arch to be founded on sound sandstone. The crown of the arch is identical to that observed in the west masonry-lined section with variable masonry block dimensions. At Sta. 7+50, the three blocks forming the keystone at the interior end of the lining have been displaced upward. The cause of this displacement is unknown. Only limited repointing of the east masonry lining will be required. The mortar used for repointing must be sensitive to the type of mortar originally used, yet be compatible with the masonry blocks.

5.7 Concrete-Lined Section

The masonry lining in the eastern 50 feet of the tunnel has been reinforced with a concrete supplemental liner. Test Pit 4 (Appendix A) showed the concrete lining to be founded on a free form footing on bedrock. Construction of the concrete lining used conventional timber form work up to El. 1434 with steel liner plate forms used to complete the arch. The purpose of the concrete supplemental liner is to insure stability of the disturbed portal masonry liner (Subsection 5.8). The concrete lining is in excellent condition with no remedial work required.

5.8 East Portal Facade

The east portal was originally constructed with the same facade structure as the west portal. Reference 3 indicates that between 1890 and 1910, the east portal facade was removed to supply building stone. Some fragments of the east facade masonry have been located at the site with one large block of the north side pilaster still in place. It is speculated by GEI that the facade may have partially collapsed prior to removal as evidenced by the generally distressed earth backfill slopes above the remaining structure, the displaced masonry liner at the remaining portal, and the remnant of remaining portal facade masonry.

Before general public access to the tunnel is permitted, the area above the east portal should be stabilized. All trees should be cleared and stumps removed. Assuming the original portal facade will not be replicated, all loose earth and rock backfill should be removed from above the portal, new dry stone masonry or concrete retaining walls constructed and new earth backfill placed to restore safety against debris falling from above the portal. Particular care must be taken to stabilize the area to the south of the portal.

6. TUNNEL REMEDIATION

6.1 General

Section 5 discusses field observations related to tunnel stability evaluation. This section addresses the specific remedial work required to permit public entry into the tunnel and to preserve the tunnel against further deterioration.

6.2 West Portal Facade

The west portal facade and earth backfill slopes require remedial work to preserve the structure. The facade itself has experienced displacement of the top courses of masonry due to tree root growth and freeze/thaw action. These displaced blocks should be removed, the tree roots eliminated, and the blocks reset for public safety. During this process, any evidence of the facade original construction methods should be recorded.

Historic project photographs show major dry laid stone masonry retaining walls abutting the facade. These walls have partially collapsed or been removed over the years. Loss of these walls has permitted erosion and loss of earth backfill over the tunnel masonry liner near the portal. Trees have been permitted to grow on top of the earth backfill slope and have caused additional distress. Remediation should include removal of trees and stumps above the portal lining, restoration of the dry laid masonry walls, and restoration of earth backfill over the tunnel lining to improve runoff and seal the masonry liner against rainwater infiltration.

6.3 West Portal Masonry Lining

The west portal masonry lining is in fair condition. The original masonry construction included mortar between the masonry blocks for stability and to seal the portal area against ground water infiltration. Over the years, the cementitious material in the mortar has been leached out by ground water seepage and the mortar sand lost. This has allowed loss of two crown blocks (Section 5.4) and a 5-foot-diameter area has been displaced downward. Due to the interlocking nature of the masonry block construction, the surrounding blocks in these distressed areas have shifted to preserve stability to the arch.

Remediation for the west portal masonry lining should include a) repointing of the masonry joints above the spring line, b) wedging of loose blocks to restore stability, and c) replacement of lost blocks. Mortar for repointing should match the color (buff) and texture (sandy) character of the original mortar. Repointing would be accomplished from a truck mounted platform providing access to the crown of the tunnel. In shallow joints, mortar would be placed using conventional mason tools such as trowels. For deep joints, multiple applications with mason tool or use of pressure injection methods will be required to inject the mortar as deep into the joints as possible.

If the missing blocks are not replaced, the surrounding blocks should be stabilized, and the rubble backfill above the arch could then be used for interpretive values during tours. Wedges for stabilizing the masonry blocks should be thin stainless steel double wedges, lead, or other material to insure long life.

6.4 Bedrock Tunnel Section

The central 600 feet of Staple Bend Tunnel consists of exposed bedrock on the sidewalls and crown. The upper 1/4 to 1/2 of the tunnel section is in a competent, brow, fine-grained massive to thin bedded sandstone. This upper sandstone (Subsection 2.3) forms a relatively stable arch for the tunnel. The only long-term risks are a) the potential for occasional fall of a slab of thinly bedded sandstone due to ground water or freeze/thaw action or b) the fall of a rock block bounded by natural joints or fault plains.

Remediation of the upper sandstone in the crown of the tunnel should include close inspection from a truck mounted platform to identify potentially unstable rock blocks or loose slabs. Any questionable rock blocks could either be removed or doweled (pinned) as required for safety and economy. This stabilization requirement is expected to be limited. If it is decided to remove a loose block, care should be taken to avoid damage to the Bethlehem Steel Company water line buried in the tunnel invert.

Condition of the tunnel sidewalls varies significantly along the tunnel. In many areas, the walls are stable requiring only limited removal of loose debris at the base of the walls. In other areas, long-term weathering of the weaker shales and siltstones has resulted in up to 6 feet undermining of the more resistant overlying strata (Section 2). These overhangs constitute a potential hazard to the public. Remediation could include removal of the more prominent overhangs by breaking the overhang back on a bevel. The limits of remediation will have to be established on a site specific basis during construction.

An alternative to breaking back the major overhangs would be to stabilize them with shoring posts. Shoring posts could be of timber or tubular steel section. Timber posts are subject to rot and would introduce a fire hazard in the tunnel. Tabular steel shoring posts (Fig. 12) would avoid the fire hazard, but would be non-period construction. The tubular steel shoring posts could, however, be interpreted as part of the life cycle of the tunnel and required for public safety.

A third option would be to do nothing, but restrict public access to a central 10-foot path through the tunnel with chain barriers to keep people away from the more dangerous areas. This option is viable only if guided tours are permitted into the tunnel.

6.5 East Portal Concrete/Masonry Lining

The east portal concrete and masonry-lined portions of the tunnel are in good condition. Other then minor repointing of the masonry-lined section, no remediation is required in this area. Repointing would be limited to the area above the springline and would use the same methods as proposed for the west masonry-lined section (Subsection 6.3).

6.6 East Portal Facade

The east portal facade has been lost, and the masonry lining has suffered major translational displacements to the north. Whether this translational displacement was due to collapse or deliberate removal of the original facade is uncertain. Further distress to the masonry arch may have occurred in 1940s during construction of the Bethlehem Steel Company water line. The concrete portion of the east portal liner appears to have been installed in the 1940s to restore stability of the masonry arch prior to or following completion of the water line.

Following loss of the facade, the earth backfill over the masonry lining experienced major erosion. Trees have developed on the slope above the portal and a large mass of bedrock and earth is sliding on the south side of the portal. Remediation at the east portal should include removal of the slide mass on the south side of the portal back to any natural bedrock exposure on the abutment. Trees, stumps, and roots should be removed from above the portal area. Retaining walls should be restored adjacent to the portal and backfilled. The retaining walls should be of such size and elevation to trap any debris falling down the slope above the portal to protect the public.

6.7 Construction Contract Form

The work exterior to the west and east portals can be reasonably defined and engineered. This work would be suitable for a lump sum-type contract.

Work required inside the tunnel is very site specific and will not lend itself to detailed engineered drawings. For work inside the tunnel, a combined unit price and time-and-material contract is recommended. This type of contract will substantially reduce engineering costs for the bid package. During construction, a knowledgeable site engineer would work closely with the contractor to specify detailed work at each point along the tunnel. This method of engineered construction will reduce the conservatism required by an engineered construction package and provide major engineering and total project cost savings.

7. ENGINEER'S COST ESTIMATE

7.1 General

Staple Bend Tunnel has been found to be in relatively good condition for a 160-year-old facility. Section 6 identified the remedial work required to be performed prior to allowing general public access to the tunnel. This section provides engineer's cost estimates (Table 1) for the remedial work required inside the tunnel only. Costs of remedial work on the west portal facade, stabilization of slopes above the east and west portals, and other exterior work are addressed by Sellards & Grigg ([Ref. 2].

7.2 West Masonry-Lined Section

Priority work required to stabilize the west masonry-lined section consists of replacing the lost crown blocks at Stas. 0+58 and 1+03. Repointing of the stone masonry above the tunnel springline is required to prevent future block falls. General cleanup of the tunnel invert in this section is a low priority item.

7.3 Bedrock Tunnel Section

Priority work required in the unlined bedrock tunnel section consists of protecting against rockfalls from the tunnel crown. This work will include wedging and barring down loose rock blocks or dowelling to secure potentially unstable larger blocks in place.

Secondary priority work includes protecting the public from rockfalls from the tunnel walls by stabilizing the major overhangs, identified in Subsection 6.4. Table 1 includes cost estimates for four options to provide the necessary protection including: a) steel shoring posts, b) timber shoring posts, c) breaking back overhanging rock blocks, or d) providing a walkway with railings to keep the public away from the rock walls.

In addition to stabilizing the major overhangs, it may be possible to apply a sealant to the weaker bedrock strata to retard weathering and slaking. This is a low priority work item as is the general tunnel invert cleanup.

7.4 East Masonry-Lined Section

Remedial work for the east masonry-lined section will consists of repointing the masonry above the springline and general cleanup of the tunnel invert. The masonry pointing is an intermediate priority item, while the general invert cleanup is a low priority item.

7.5 East Concrete-Lined Section

The concrete-lined section is in good condition. Other than the general cleanup of the tunnel invert, no remedial work is required in this section.

REFERENCES

[1] Sellards & Grigg, Inc. (1990) "Staple Bend Tunnel, Preliminary Site Visit Report," February 27.

[2] Sellards & Grigg, Inc. (1991) "Staple Bend Tunnel, Historic Structure Report," April.

[3] Clemensen, A. Berke (1990) "Staple Bend Tunnel, Allegheny Portage Railroad National Historic Site," July.

TABLES

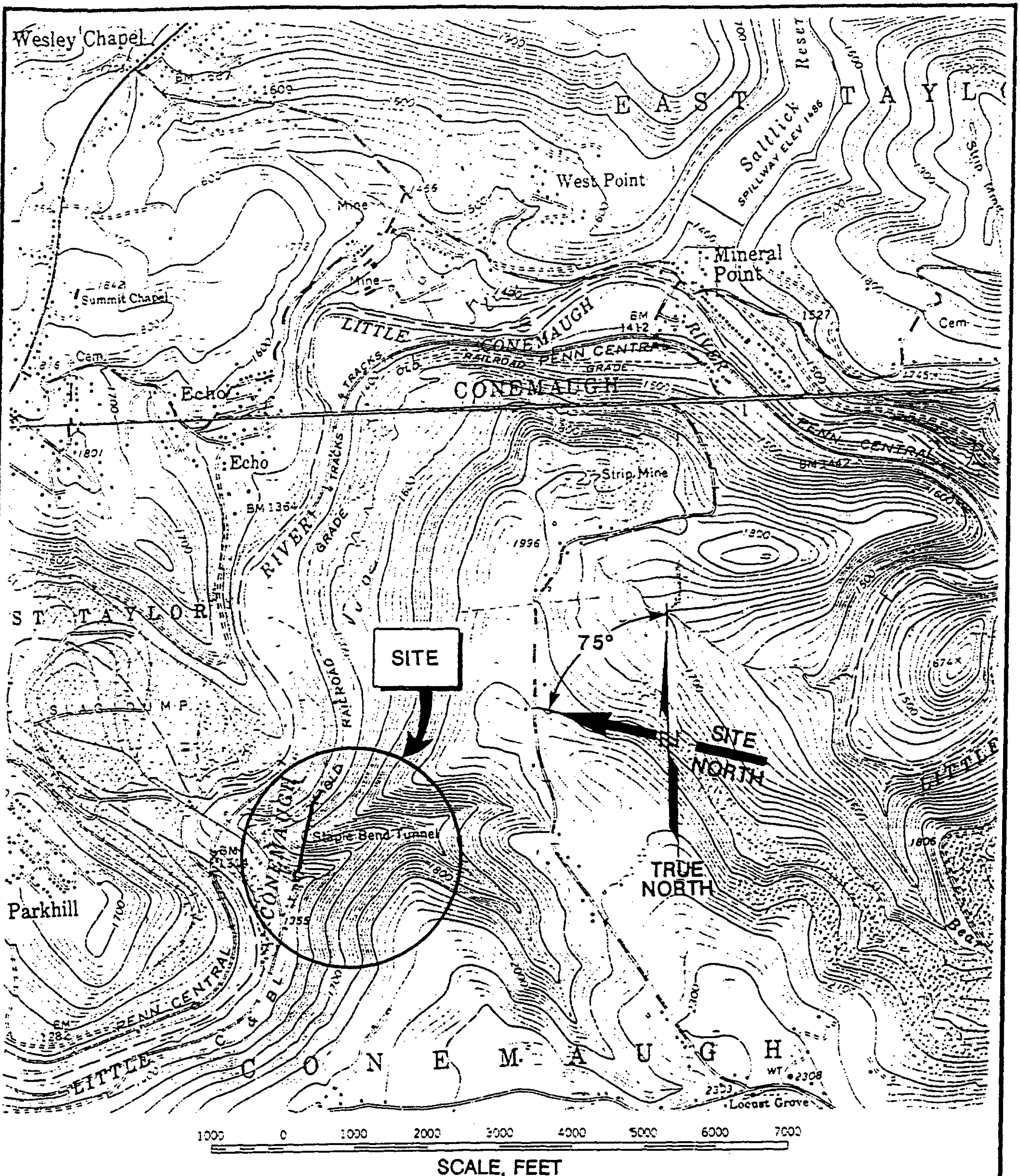
TABLE 1 - ENGINEER'S COST ESTIMATE
Remedial Work
Staple Bend Tunnel

Section	Priority*	Cost**
1. West Masonry-Lined Section (150 feet)		
a. Replace Lost Blocks	1	$ 3,500
b. Repointing	1	11,500
c. Tunnel Invert Cleanup	3	3,500
2. Bedrock Tunnel Section (600 feet)		
a. Tunnel Crown		
(1) Wedging and Barring	1	20,700
(2) Dowels	1	23,000
b. Tunnel Walls		
(1) Steel Shoring Post Option	2	12,500
(2) Timber Shoring Post Option	2	7,200
(3) Break Back Overhangs Option	2	69,000
(4) Fenced Path Option	2	20,700
(5) General Rock Removal	2	20,000
(6) Sealing Lower Red Sandstone	3	13,800
c. Tunnel Invert Cleanup	3	13,800
3. East Masonry-Lined Section (100 feet)		
a. Repointing	2	3,500
b. Tunnel Invert Cleanup	3	2,300
4. East Concrete-Lined Section (50 feet)		
a. Tunnel Invert Cleanup	3	1,200

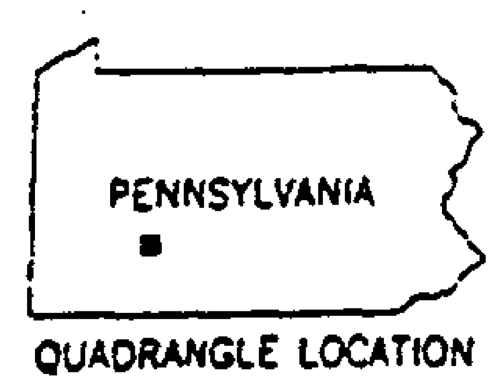
*Priority
1. Required for public safety
2. Optional Item for public safety
3. Not required for public safety

** Costs include contingency of 15%.
No mobilization/demobilization, field office, or insurance bond included.

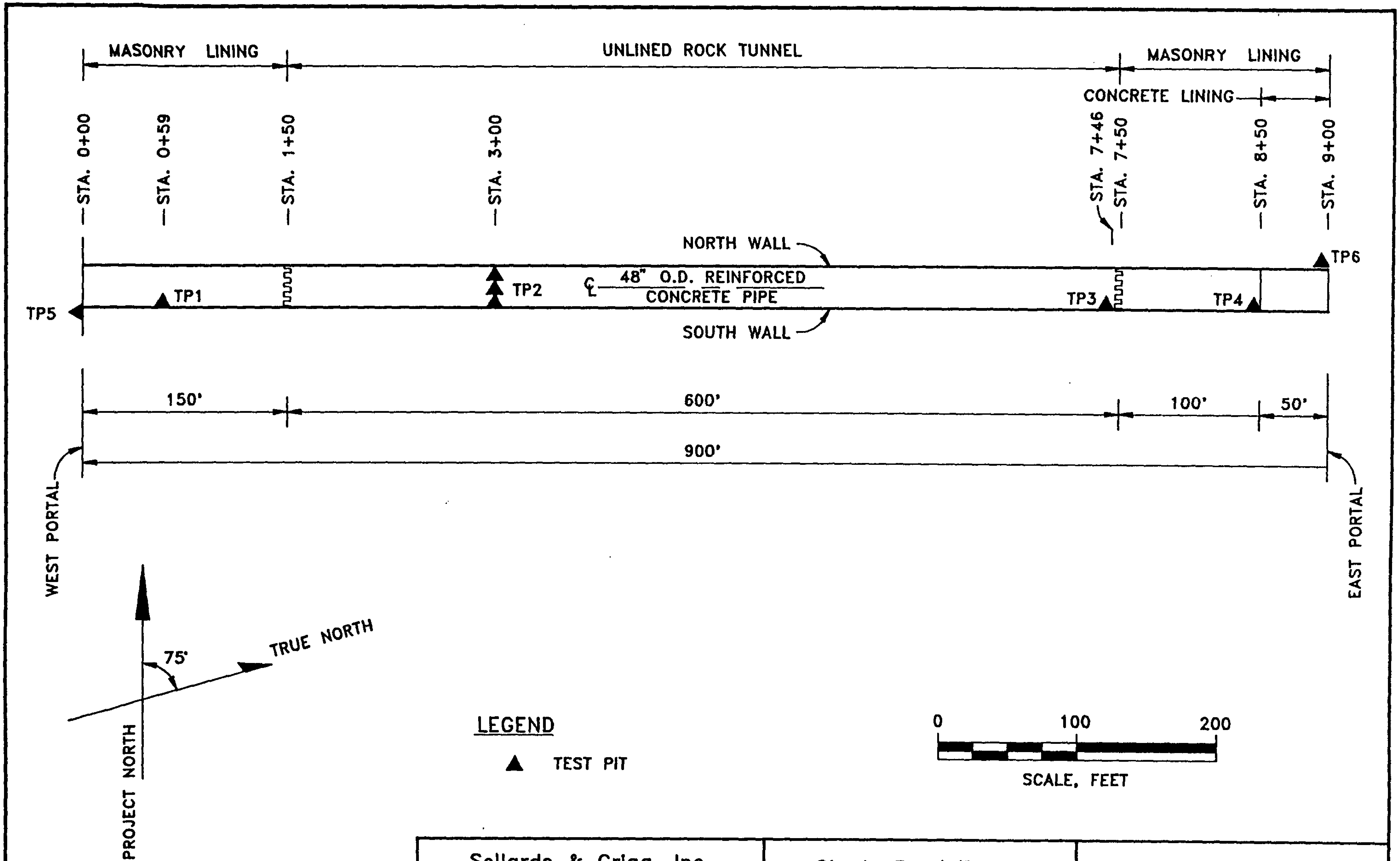
FIGURES



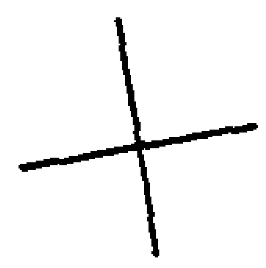
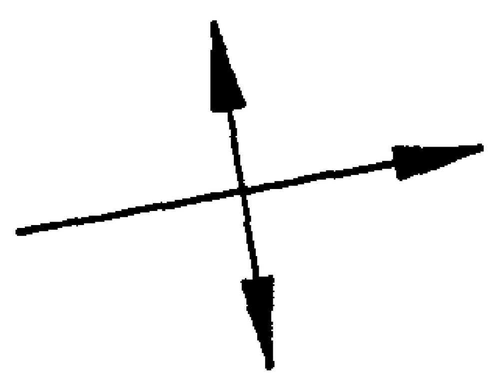
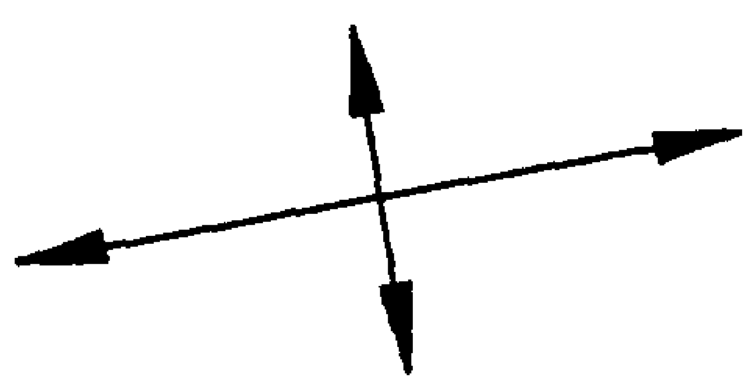
Map is taken from U.S.G.S. Topographic 7.5 Minute Series Map of Nanty Glo & Geistown, Pennsylvania Quadrangle, 1972.
Datum is Mean Sea Level (M.S.L).
Contour Interval is 20 Feet.

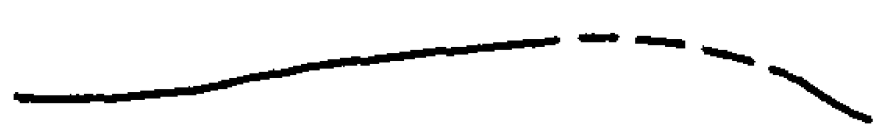
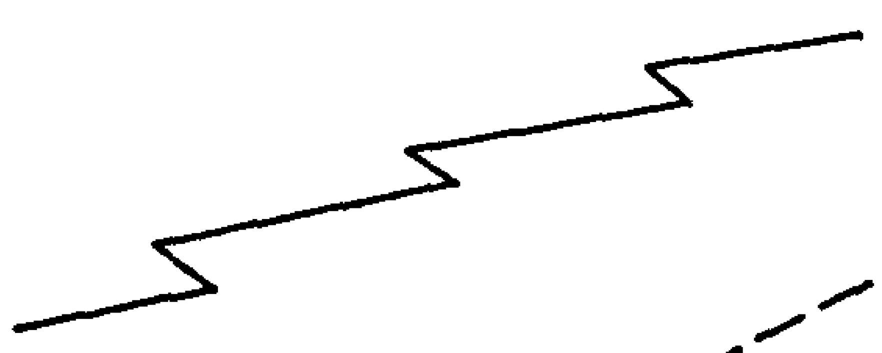
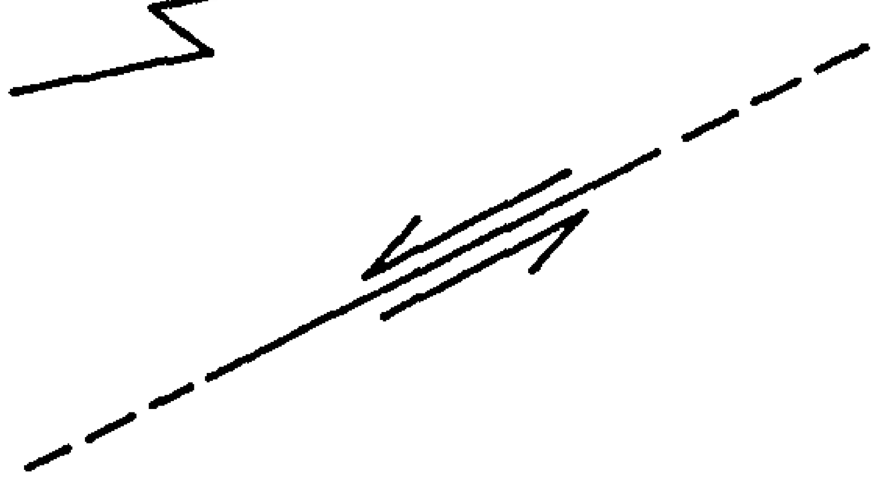


Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	SITE LOCATION MAP
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 1



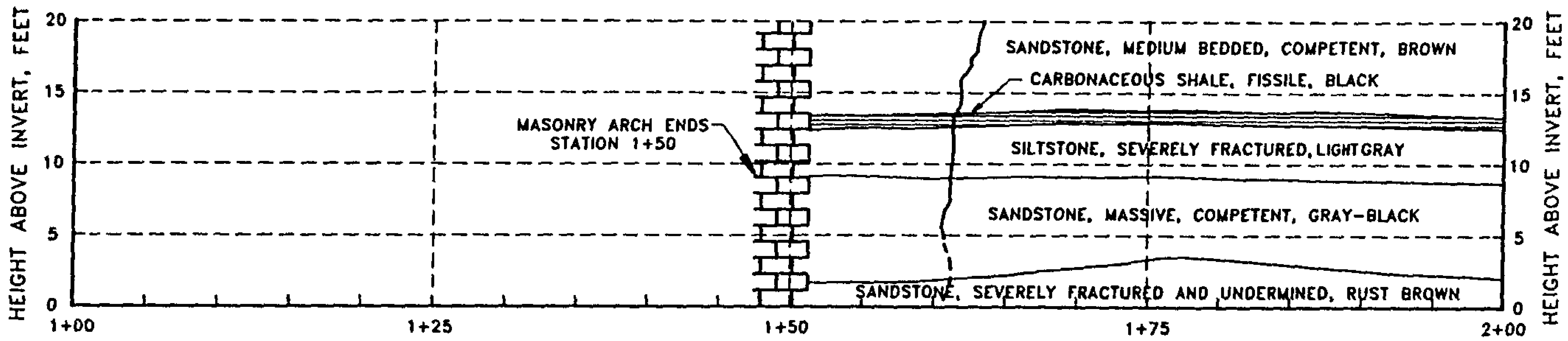
Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	SITE MAP
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 2

MAP SYMBOL	DESCRIPTION
	STRIKE AND DIP (DEGREES) OF BEDDING OR BEDDING PLANE JOINTS
	STRIKE AND DIP (DEGREES) OF MAJOR JOINTS
	HORIZONTAL JOINT
	ANTICLINE SHOWING TRACE OF AXIAL PLANE AND PLUNGE OF AXIS (LONG DIMENSION)
	DOUBLEY PLUNGING ANTICLINE SHOWING CULMINATION

PROFILE SYMBOL	DESCRIPTION
	STRATA CHANGE, DASHED WHERE INFERRED OR TRANSITIONAL
	FACIES CHANGE, (LATERAL GRADATIONAL TRANSITION)
	FAULT OR SHEAR ZONE, DASHED WHERE INFERRED OR INDISTINCT, ARROWS INDICATE RELATIVE DIRECTION OF DISPLACEMENT

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	LEGEND GEOLOGIC MAP AND PROFILE SYMBOLS
Φ GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 3

NORTH WALL PROFILE

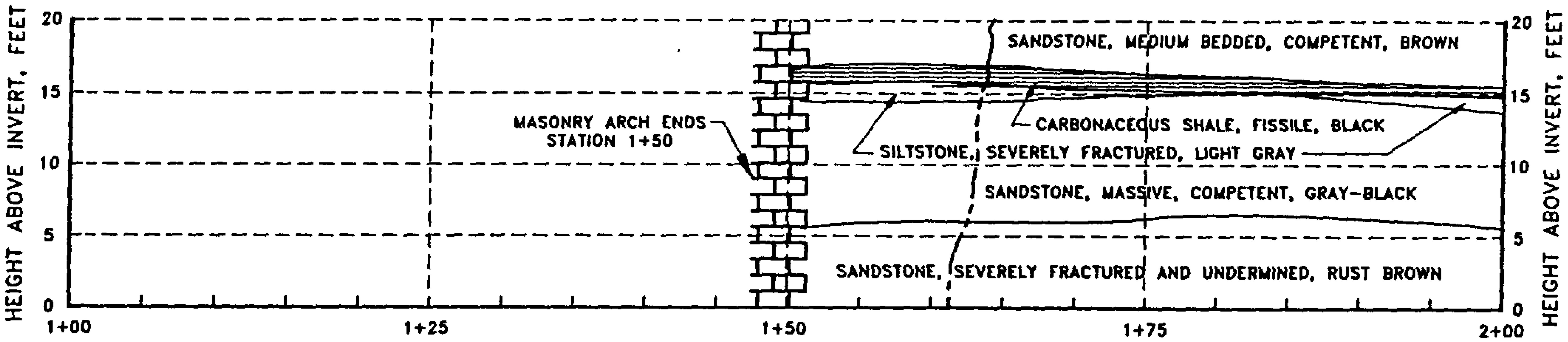


BASELINE STATIONING

PLAN AT SPRINGLINE

TUNNEL ALIGNMENT N15E

SOUTH WALL PROFILE



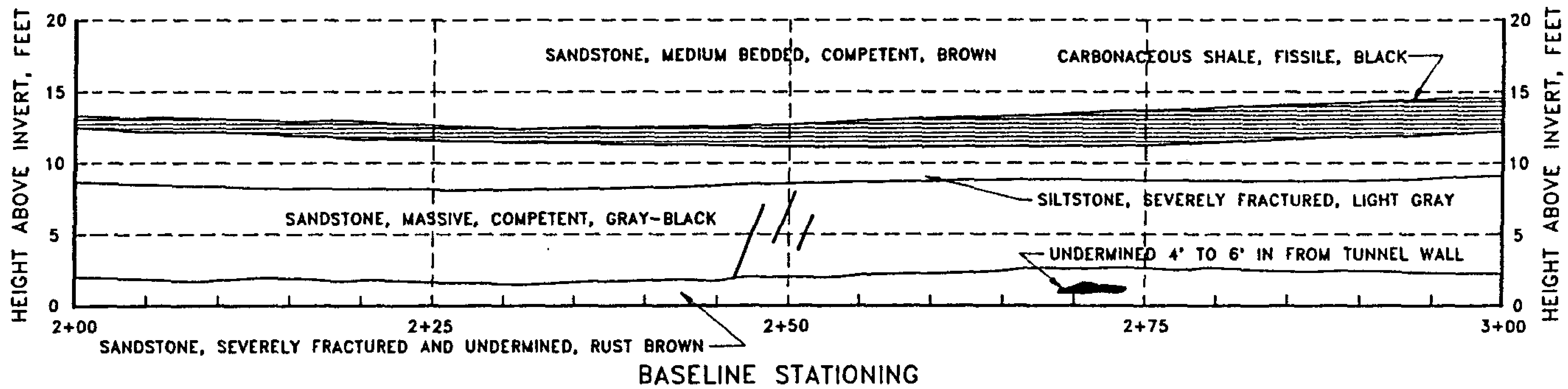
BASELINE STATIONING

NOTES

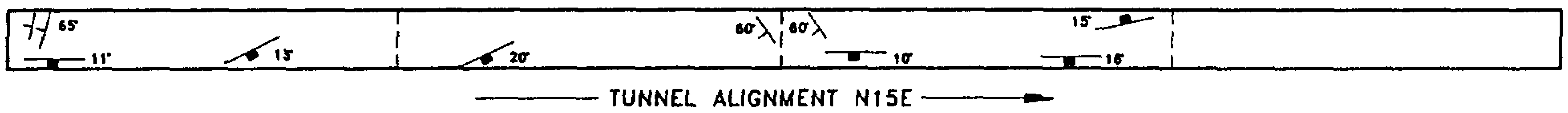
1. VERTICAL AND HORIZONTAL SCALE: 1 In. = 10 ft.
2. PROFILE GEOLOGIC FEATURES ARE SHOWN WITH APPARENT DIP. PLAN MAP SYMBOLS ARE SHOWN WITH TRUE DIP.
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 1 OF 7
Φ GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 4

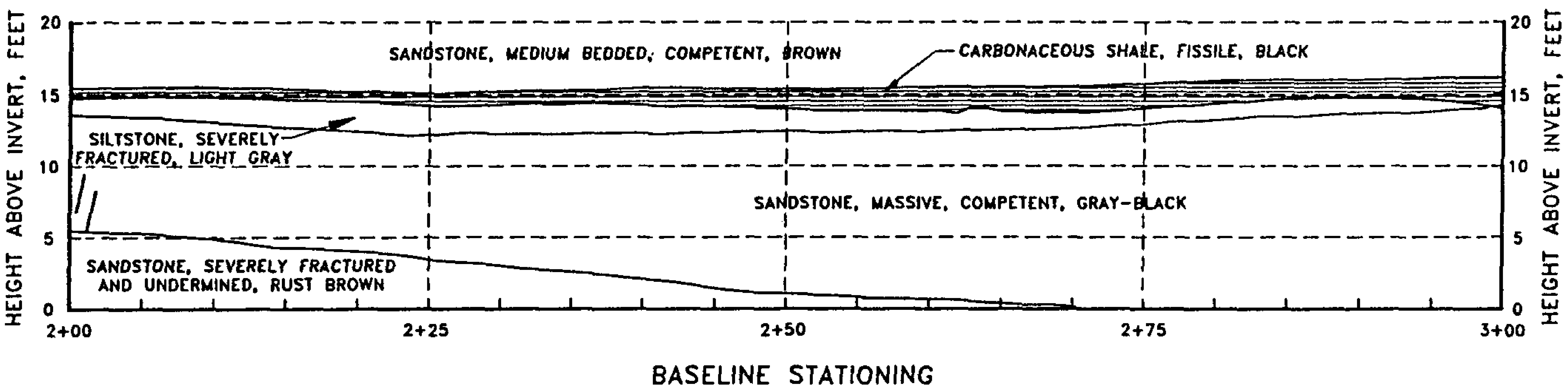
NORTH WALL PROFILE



PLAN AT SPRINGLINE



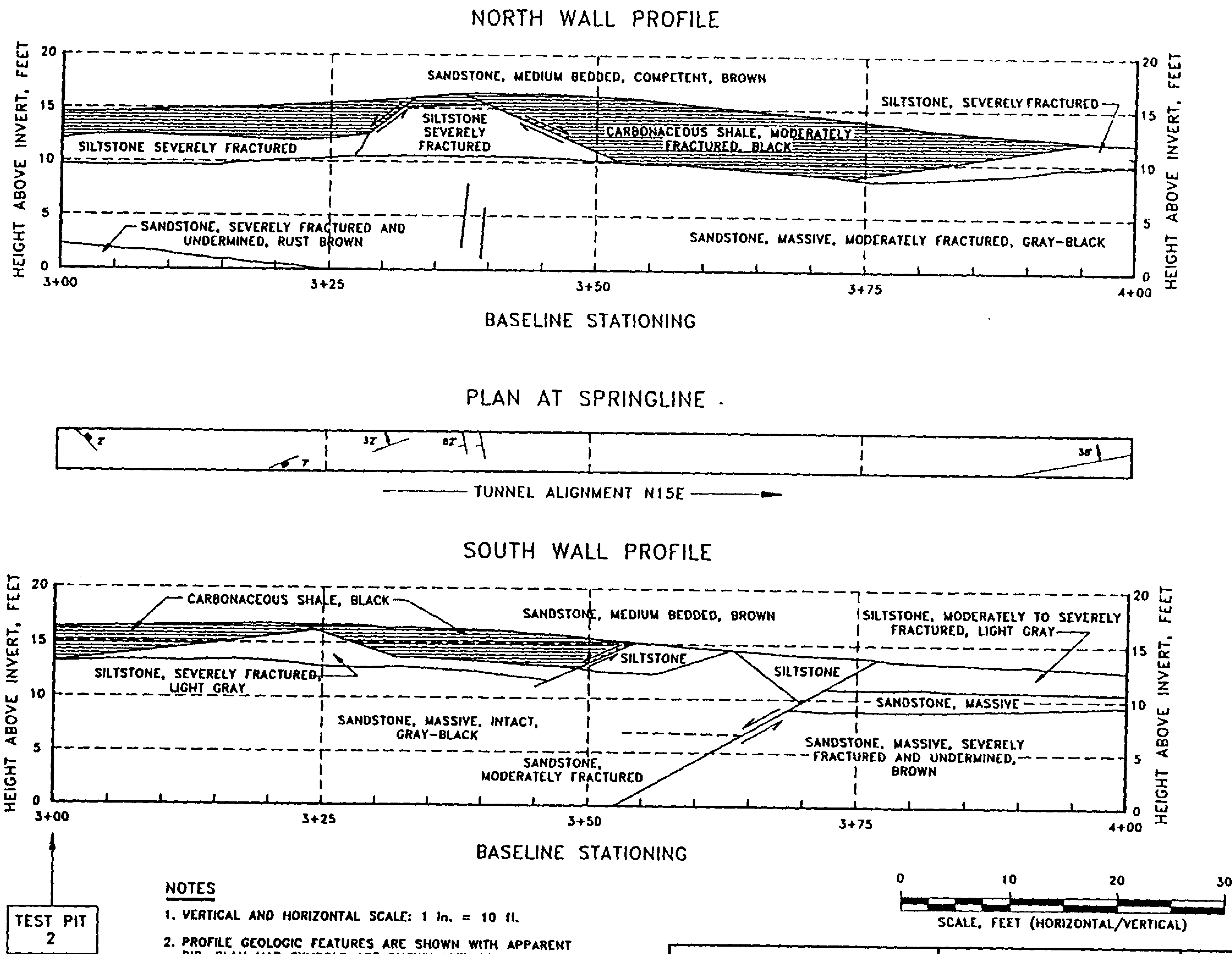
SOUTH WALL PROFILE



NOTES

1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
2. PROFILE GEOLOGIC FEATURES ARE SHOWN WITH APPARENT DIP. PLAN MAP SYMBOLS ARE SHOWN WITH TRUE DIP.
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 2 OF 7
Φ GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 5

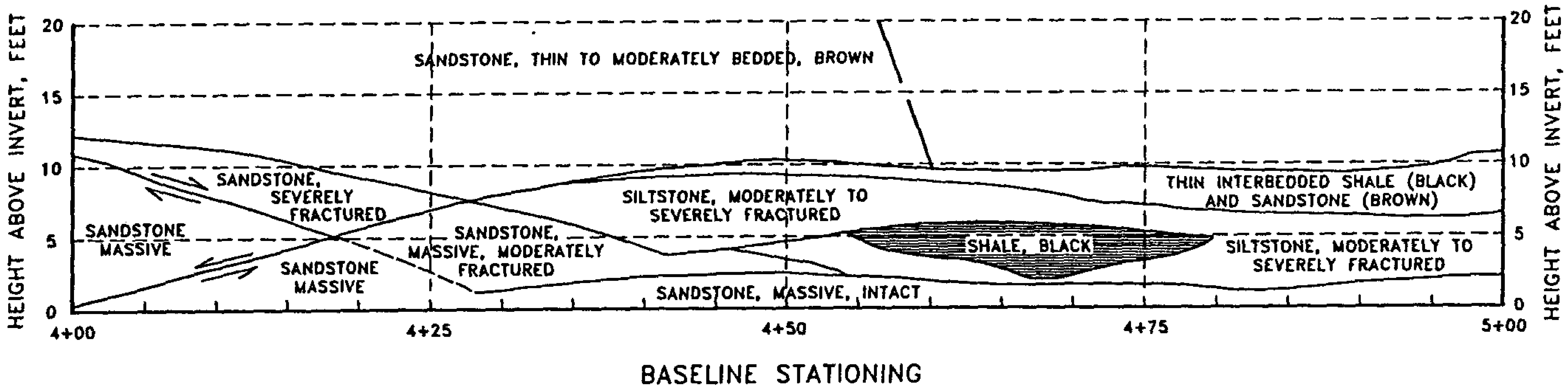


NOTES

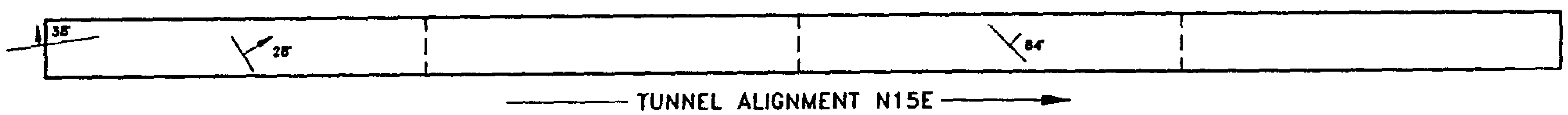
1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
2. PROFILE GEOLOGIC FEATURES ARE SHOWN WITH APPARENT DIP. PLAN MAP SYMBOLS ARE SHOWN WITH TRUE DIP.
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 3 OF 7
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 6

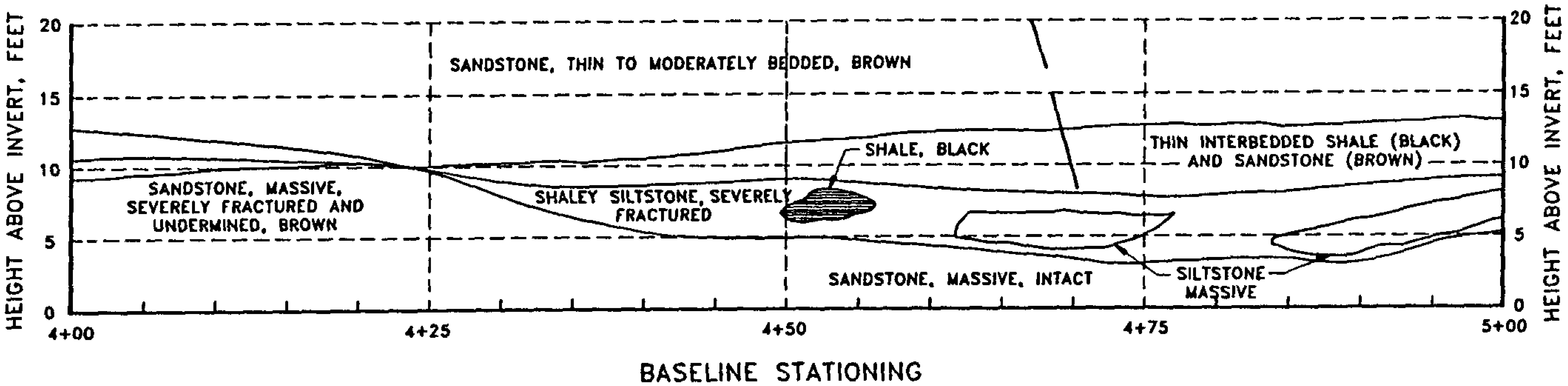
NORTH WALL PROFILE



PLAN AT SPRINGLINE



SOUTH WALL PROFILE



NOTES

1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
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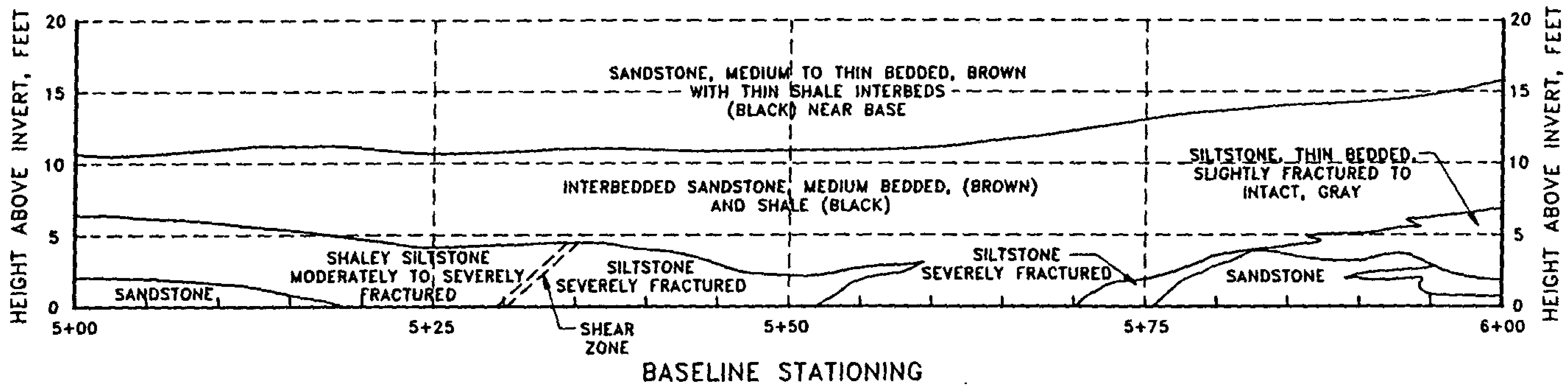
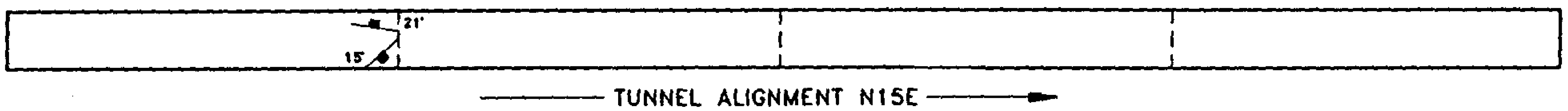
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 4 OF 7
Φ GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 7

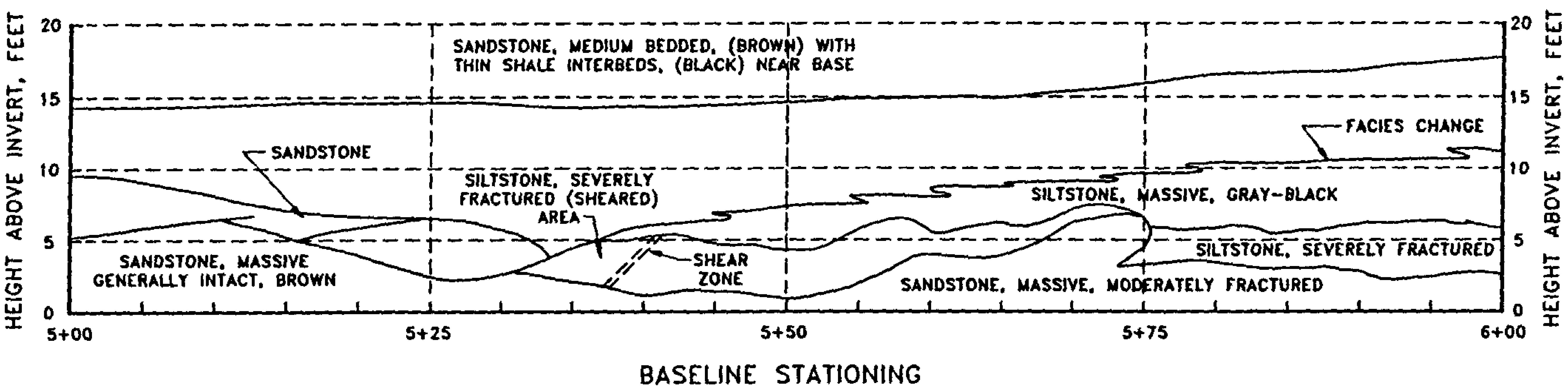
NORTH WALL PROFILE



PLAN AT SPRINGLINE



SOUTH WALL PROFILE



NOTES

1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
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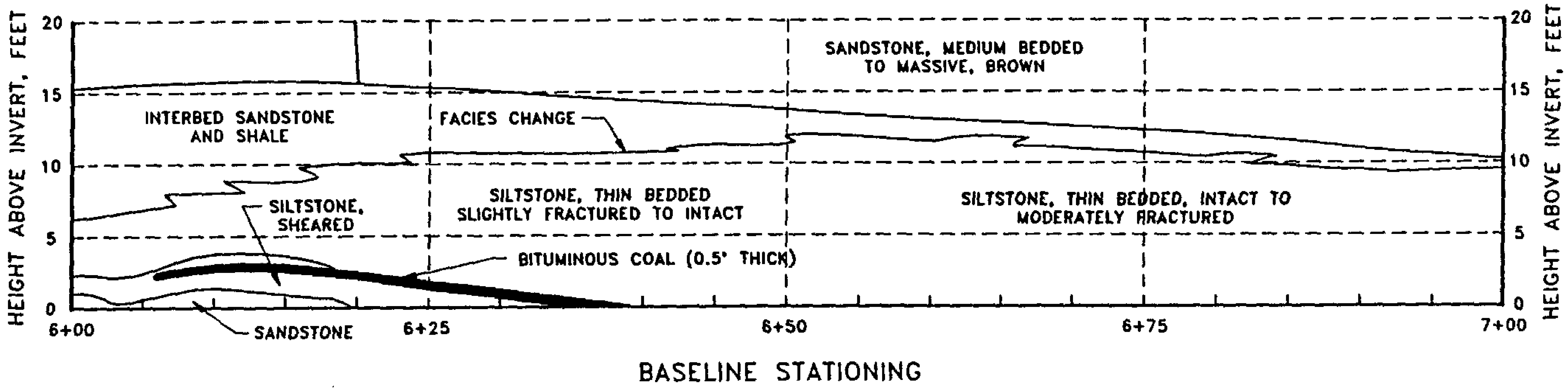
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 5 OF 7
Φ GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 8

NORTH WALL PROFILE



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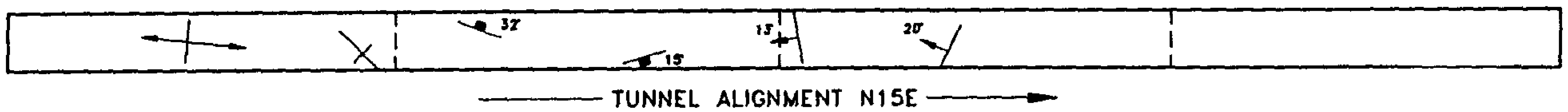

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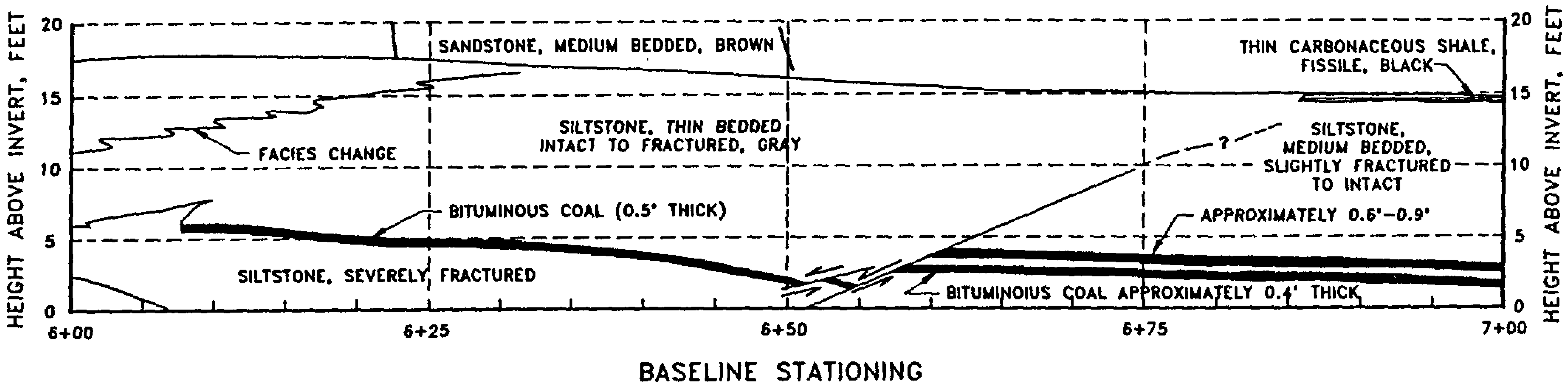


0 10 20 30

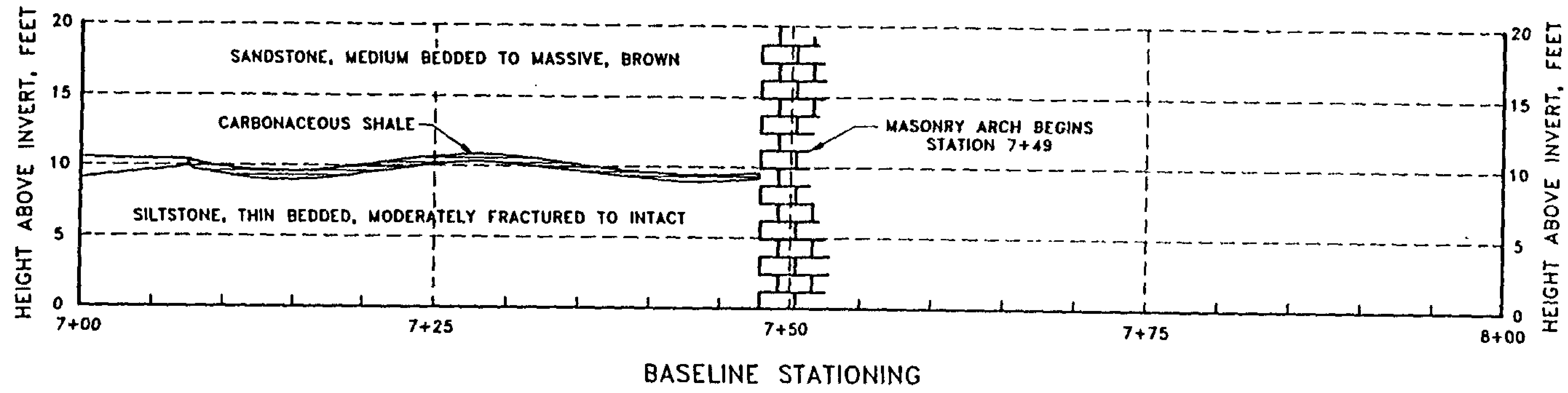
SCALE, FEET (HORIZONTAL/VERTICAL)

NOTES

1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
2. PROFILE GEOLOGIC FEATURES ARE SHOWN WITH APPARENT DIP. PLAN MAP SYMBOLS ARE SHOWN WITH TRUE DIP.
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 6 OF 7
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 9

NORTH WALL PROFILE



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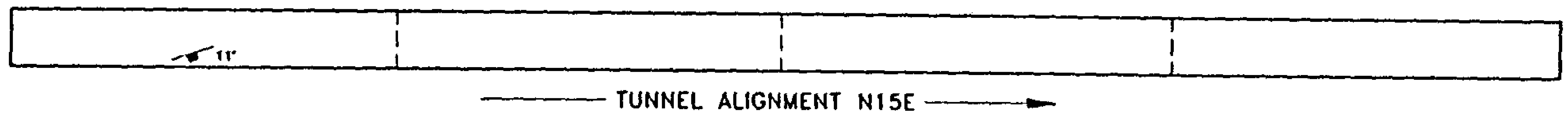
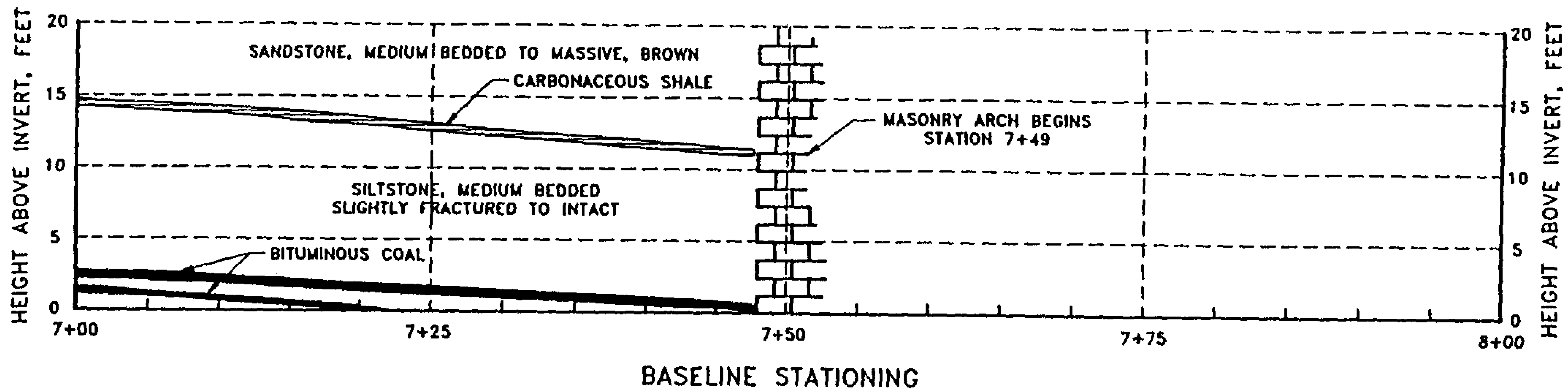


SOUTH WALL PROFILE

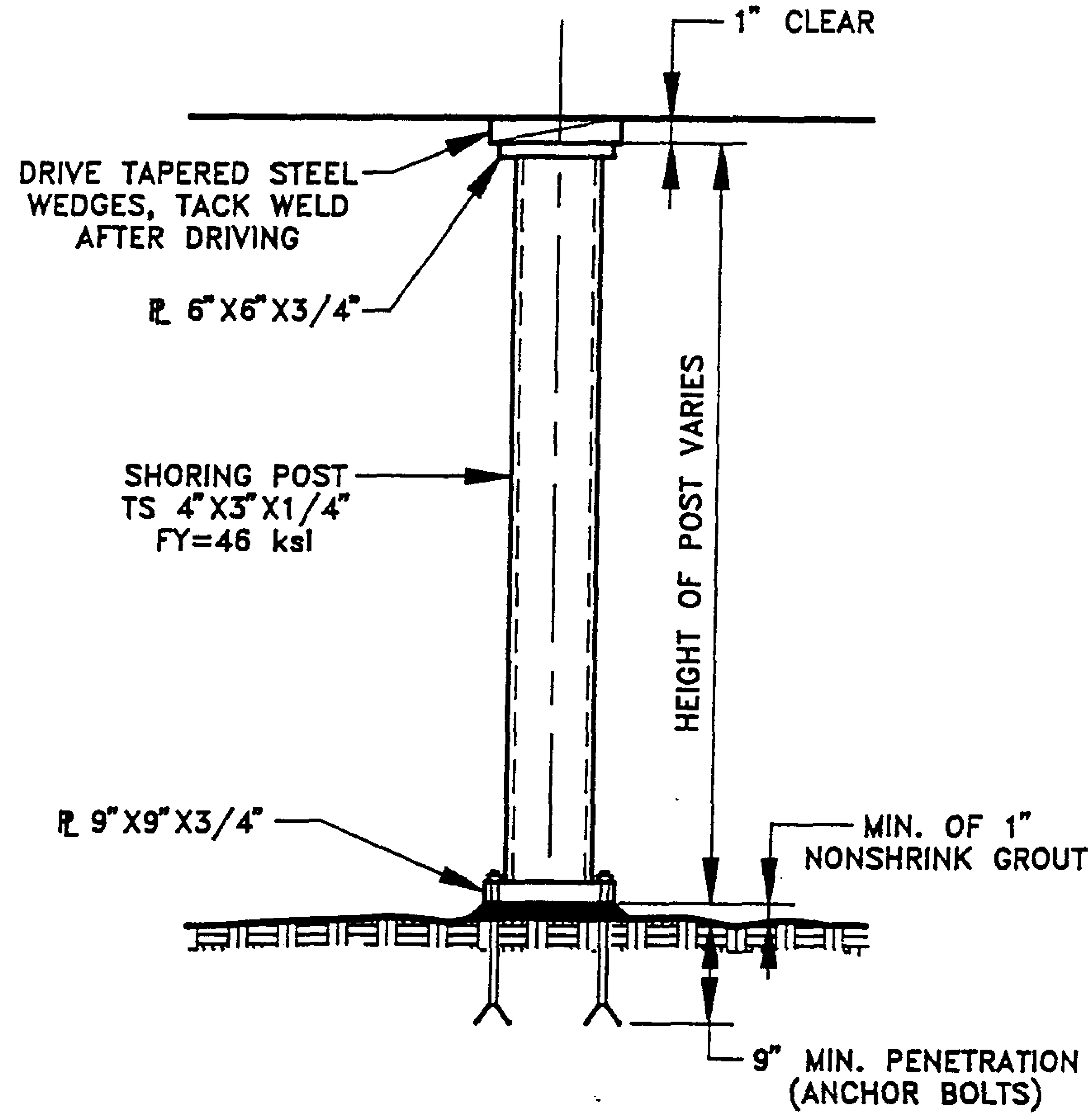


TEST PIT 3

NOTES

1. VERTICAL AND HORIZONTAL SCALE: 1 in. = 10 ft.
2. PROFILE GEOLOGIC FEATURES ARE SHOWN WITH APPARENT DIP. PLAN MAP SYMBOLS ARE SHOWN WITH TRUE DIP.
3. PROFILES ARE SHOWN LOOKING NORTH.
4. FOR EXPLANATION OF MAP AND PROFILE SYMBOLS, SEE LEGEND, FIG. 3.

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	GEOLOGIC PROFILES SHEET 7 OF 7
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 10



NOT TO SCALE

Sellards & Grigg, Inc. Lakewood, Colorado	Staple Bend Tunnel National Park Service Pennsylvania	SHORING POST DETAIL
GEI Consultants, Inc.	Project 90259	Nov. 16, 1990 Fig. 12

APPENDIX A

Test Pit Logs
August 21 - 24, 1990

Note: See Photograph Nos. 1 through 6 Appendix C.

TABLE A1 - TEST PIT LOGS
Staple Bend Tunnel
Johnstown, Pennsylvania

Test Pit No.	Station	Location	Description of Findings
TP1	0+59	Base of west portal arch at base of right (south) wall.	Masonry block arch wall in this area extends to a depth of about 2.6 feet below present invert. Tunnel invert soil (fill) consists of clayey gravel and sand. Lowermost masonry arch blocks are supported on a flat bedrock "shelf" comprised of sandstone. A 0-0.3 feet thick layer of silty fill was present between the masonry arch wall and bedrock. This soil appears to have been placed as a leveling medium prior to placement of the initial course of masonry blocks.
TP2	3+00	Excavation performed across full width of tunnel invert	The depth of this excavation varied from 1.6 to 2.6 feet. On the southern end of the test pit, fractured sandstone was encountered at a depth of 2.6± feet. A 48-inch-O.D. concrete water main was encountered near the center of the excavation, located about 1.0 feet right of the surveyed centerline of the tunnel. The top of the pipe was encountered at a depth of 1.6 feet. The invert of the pipe is, therefore, estimated to be 5.6 feet below present tunnel invert grade. Pipe bedding if present below the pipe was not observed. The north end of the test pit was terminated in the invert soils (fill) at depths ranging from about 0.5 to 2 feet. The invert soils (fill) consisted of clayey sand and gravel.

TABLE A1 - TEST PIT LOGS
Staple Bend Tunnel
Johnstown, Pennsylvania

Test Pit No.	Station	Location	Description of Findings
TP3	7+46	West end of east portal arch at base of right south (wall).	Masonry block arch wall in this area extends to a depth of 1.2 feet below present tunnel invert. Invert soil (fill) consists of clayey sand and gravel. Lowermost masonry arch blocks are directly supported on a bedrock "shelf" comprised of fractured siltstone.
TP4	8+50	West end of concrete lining at base if right (south) wall.	The concrete-lined section consists of two poured 5-foot-high footing walls supporting a formed concrete arch. The footing wall is supported by a one-foot-thick free-formed, continuous footing which was poured against the masonry arch prior to the wall construction. The top of the footing is less than 0.2 feet below the tunnel invert. The width of the footing is about 2.8 feet. The footing is supported on clayey gravel fill and is "keyed" along the top to accept the poured footing wall. Standing water was encountered in the excavation at the elevation of the bottom of the footing.
TP5	0+00	West portal facade, at base of ornamental column	The column (and facade) are constructed of cut and dressed sandstone. The base of the column consists of 1.3 feet high by 1.3 feet deep by 3.5 feet long blocks which extend to a depth of 3.7 feet below the present invert. The lowermost block is supported on hard, competent sandstone. The sandstone appears to step downward slightly immediately adjacent to the base blocks probably as part of the leveling effort to place the first course of blocks forming the facade.

TABLE A1 - TEST PIT LOGS
Staple Bend Tunnel
Johnstown, Pennsylvania

Test Pit No.	Station	Location	Description of Findings
TP6	8+99 approx.	North side of the east portal arch looking out of the tunnel, the test pit is in the 8 to 11 o'clock position.	This test pit was performed to remove soil fill from the top of the archway and examine the condition of the facier blocks at or near the edge of the arch. The position of the newly uncovered masonry blocks inward from the portal opening suggests that this portion of the masonry essentially moved together with the blocks at the face of the arch rather than the facier blocks moving or pivoting independently from the interior blocks.

FIELD OBSERVATION REPORT

PROJECT Staple Bend Tunnel

CLIENT Sellards & Grigg

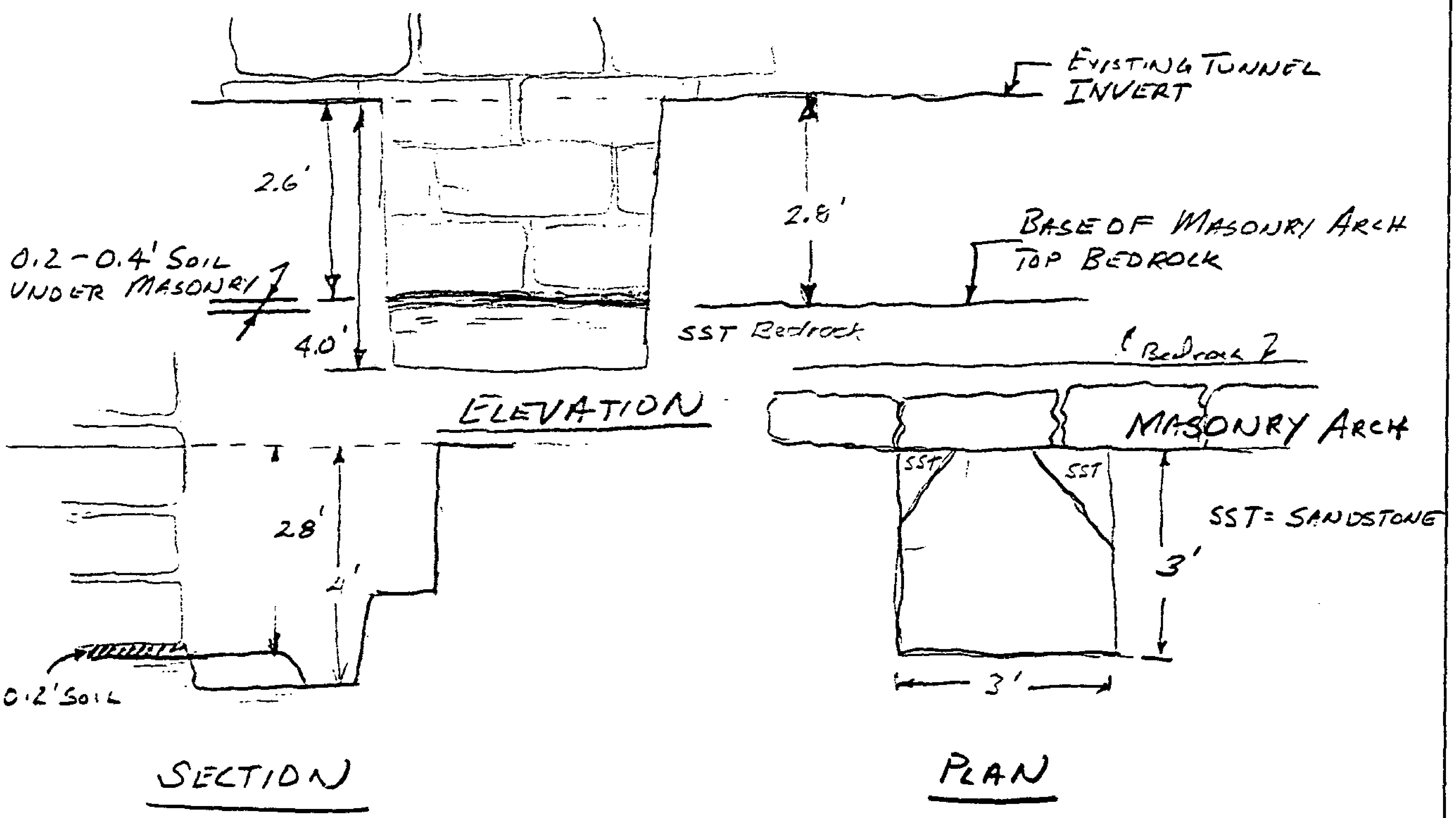
~~CONTRACTOR~~ TEST PIT LOG TP-1, STA 0+59

Date 21-24 Aug 90

Report No. TP 1

Project No. 90259

Page 1 of 6



TEST PITS EXCAVATED BY CHARLES MERLO, INC

By W. Pitt App'd [signature]

Form 4.3.1-1B JUL 88

FIELD OBSERVATION REPORT

PROJECT Staple Bend Tunnel

CLIENT Sellards & Grigg

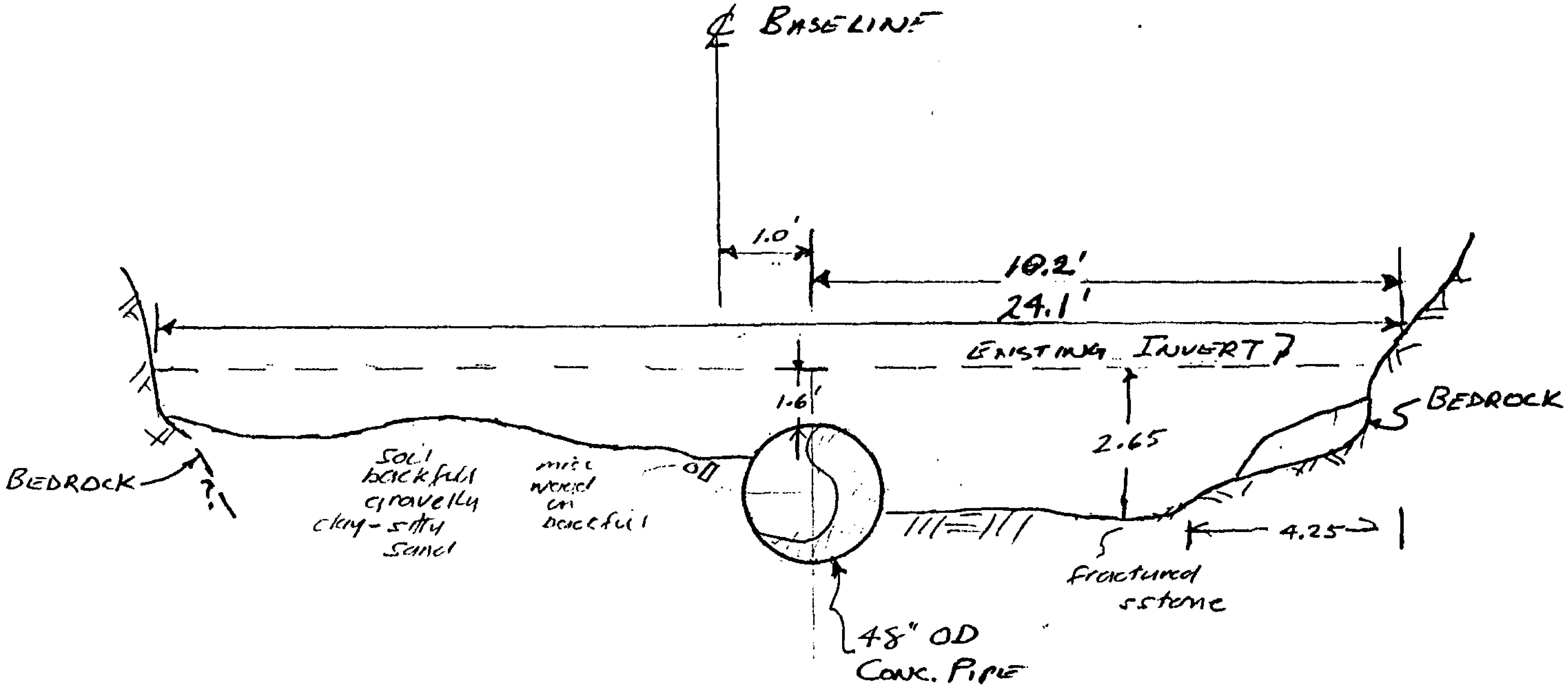
~~CONTRACTOR~~ Test Pit Log TP2, STA. 3+00

Date 21-24 Aug 90

Report No. TP2

Project No. 90259

Page 2 of 6



PROFILE LOOKING EAST

By W. Pitt

App'd

FIELD OBSERVATION REPORT

PROJECT Staple Bend Tunnel

CLIENT Sellards & Grigg

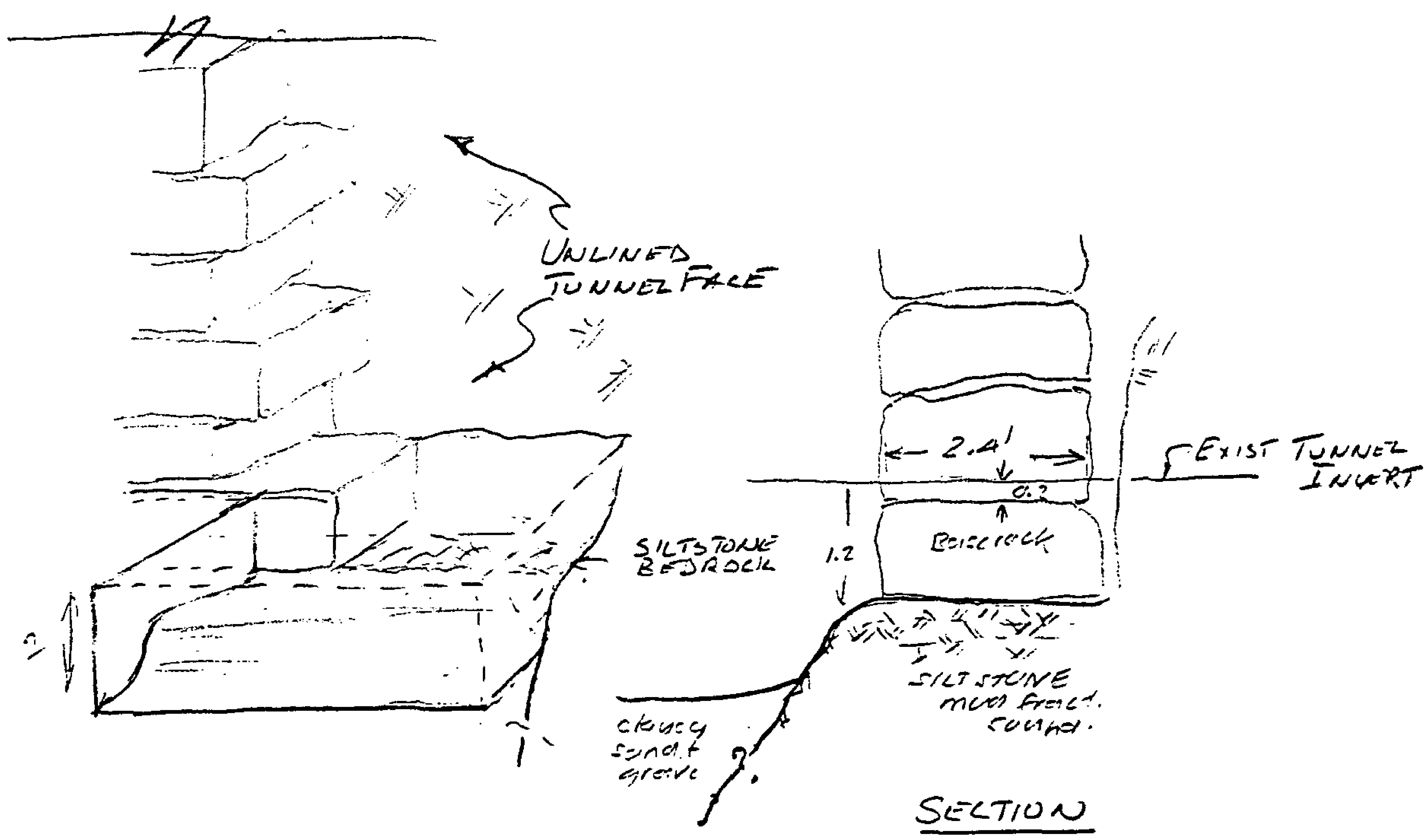
CONTRACTOR Test Pit Log TP3, STA 7+46

Date 21-24 Aug 90

Report No. TP3

Project No. 90259

Page 3 of 6



Isometric View

Looking South

By W. Pitt App'd

Form 4.3.1-1B JUL 88

FIELD OBSERVATION REPORT

PROJECT Staple Bend Tunnel

CLIENT Sellards & Grigg

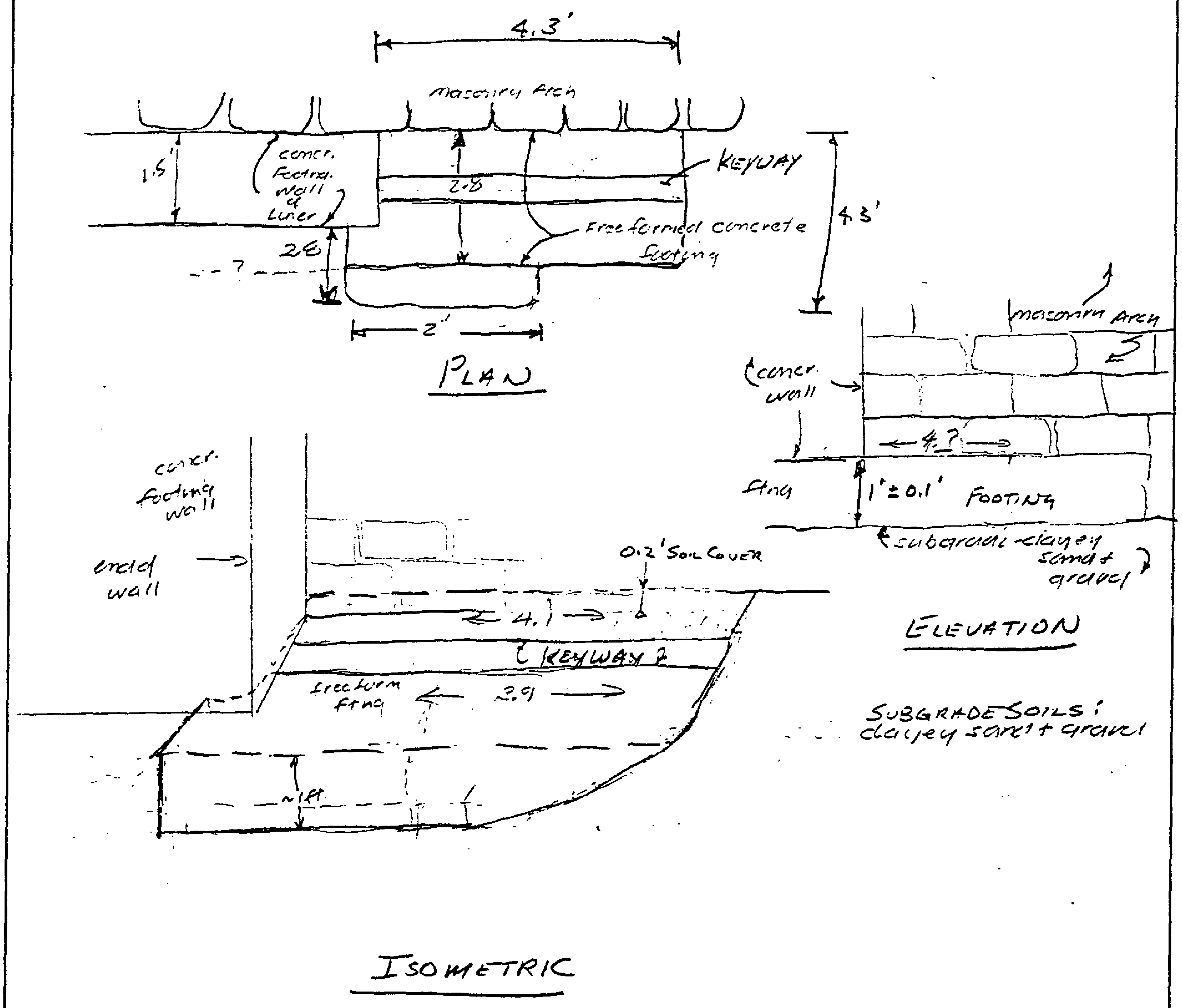
CONTRACTOR Test Pit Log TP-4 STA 8+50

Date 21-24 Aug 90

Report No. TP-4

Project No. 90259

Page 4 of 6



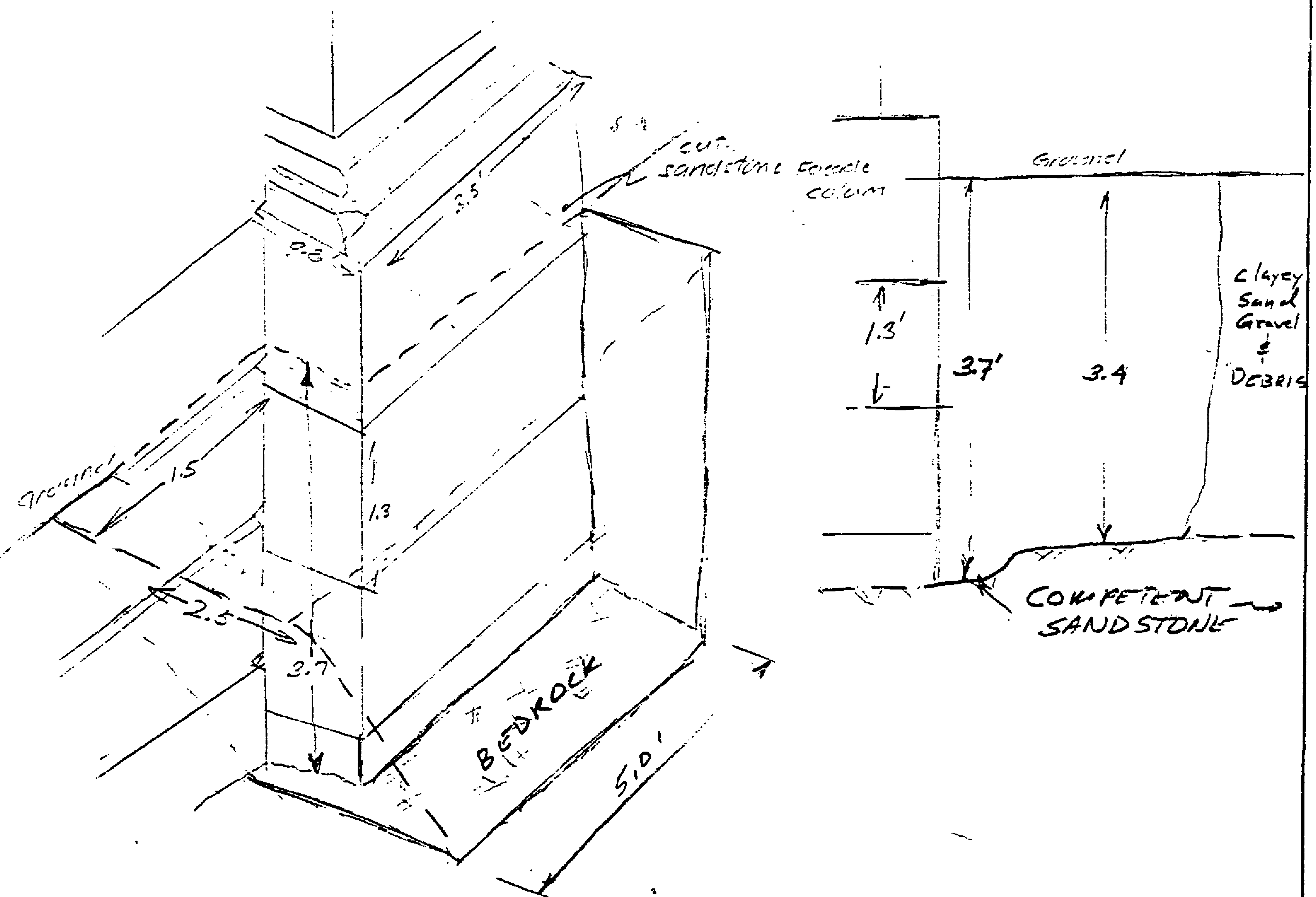
Form 4.3.1-1B JUL 88

By W. Pitt App'd

FIELD OBSERVATION REPORT

PROJECT Staple Bend Tunnel
CLIENT Sellards & Grieg
~~CONTRACTOR~~ Test Pit Log TP5 STA 0+00

Date 21-24 Aug 90
Report No. TP-5
Project No. 90259
Page 5 of 6



South Side
West Portal Facade

By W Pitt App'd [signature]

Form 4.3.1-1B JUL 88

FIELD OBSERVATION REPORT

PROJECT STAPLE BEND TUNNEL

CLIENT SELLARDS & GRIGG

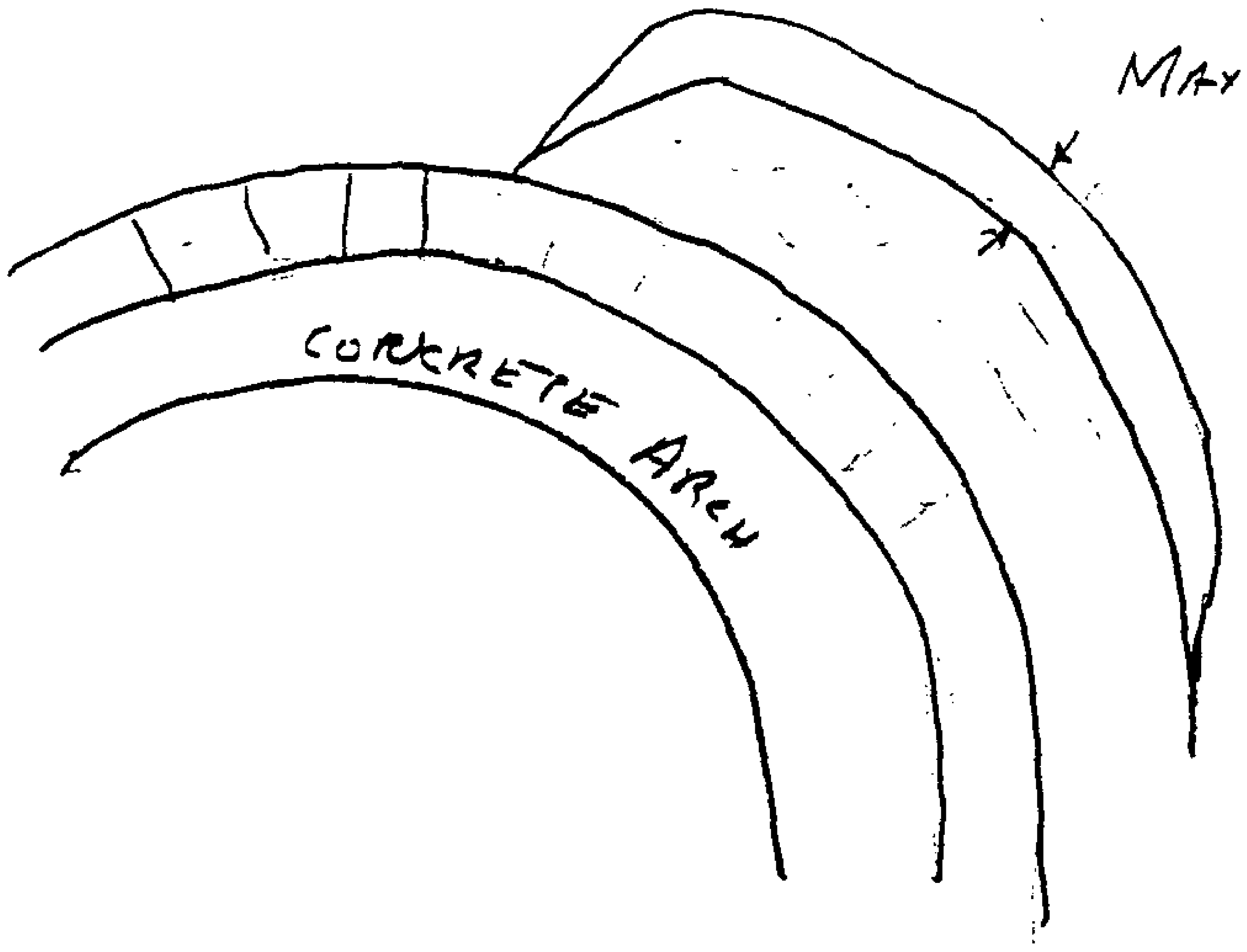
~~CONTRACTOR~~ TEST PIT LOG TP6, STA 8+99

Date 21-24 AUG 90

Report No. TP6

Project No. 90259

Page 6 of 6



TOP OF MASONRY ARCH
WEST PORTAL

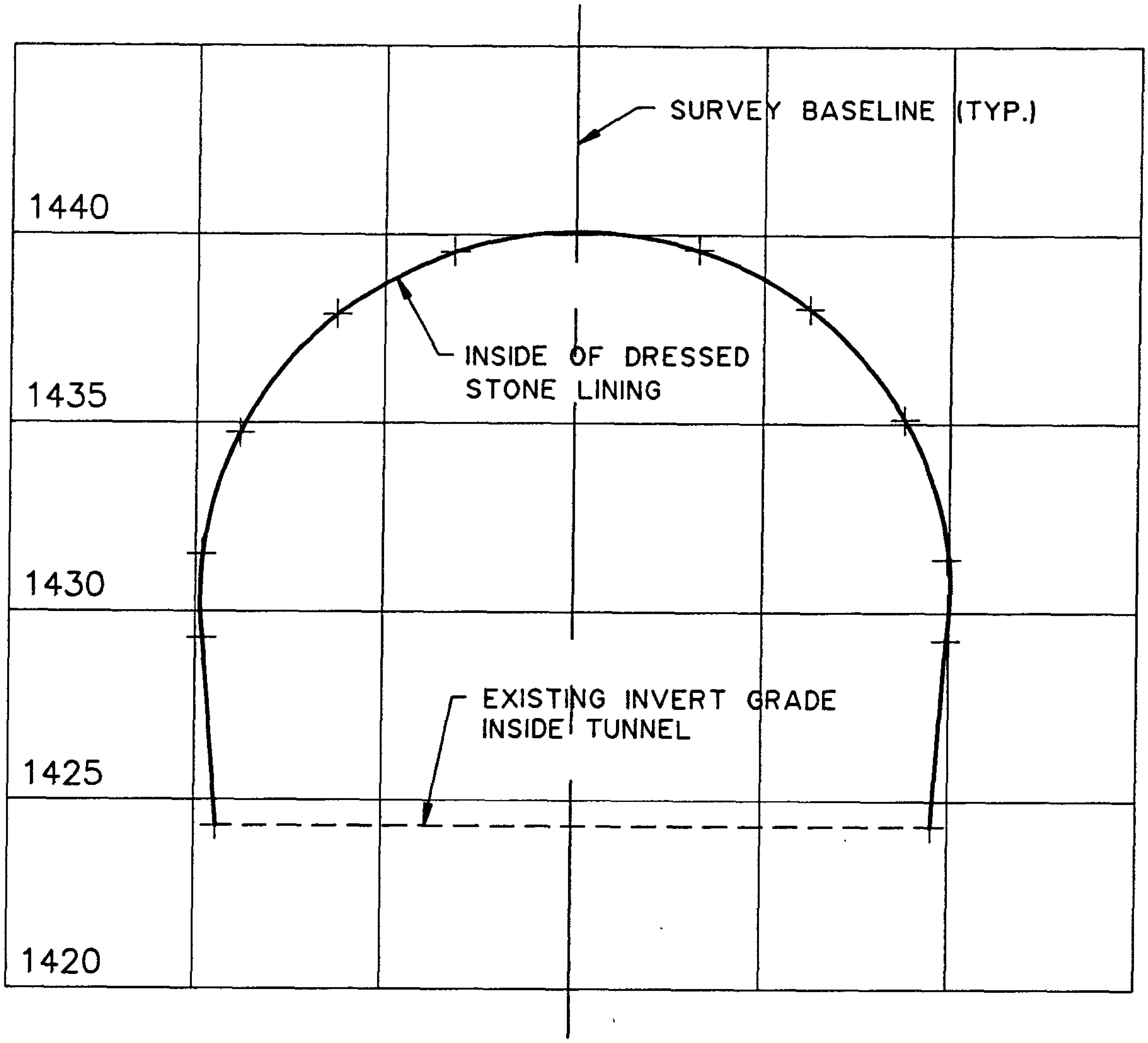
PIT EXCAVATED TO DETERMINE IF ALL BLOCKS OF MASONRY ARCH WERE DISPLACED, OR ONLY THE OUTERMOST BLOCKS. IT WAS OBSERVED THAT ALL BLOCKS EXPOSED

By W. PITT App'd [signature]

APPENDIX B

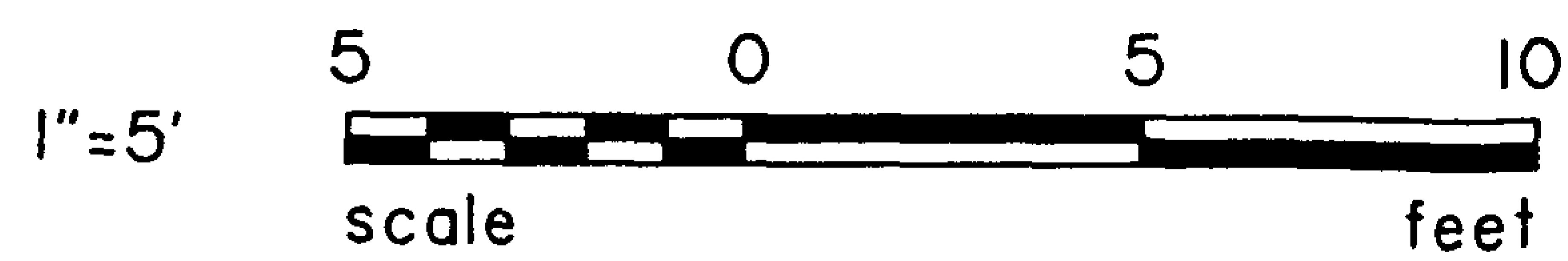
Tunnel Profile and Cross Sections
Survey by EADS Group

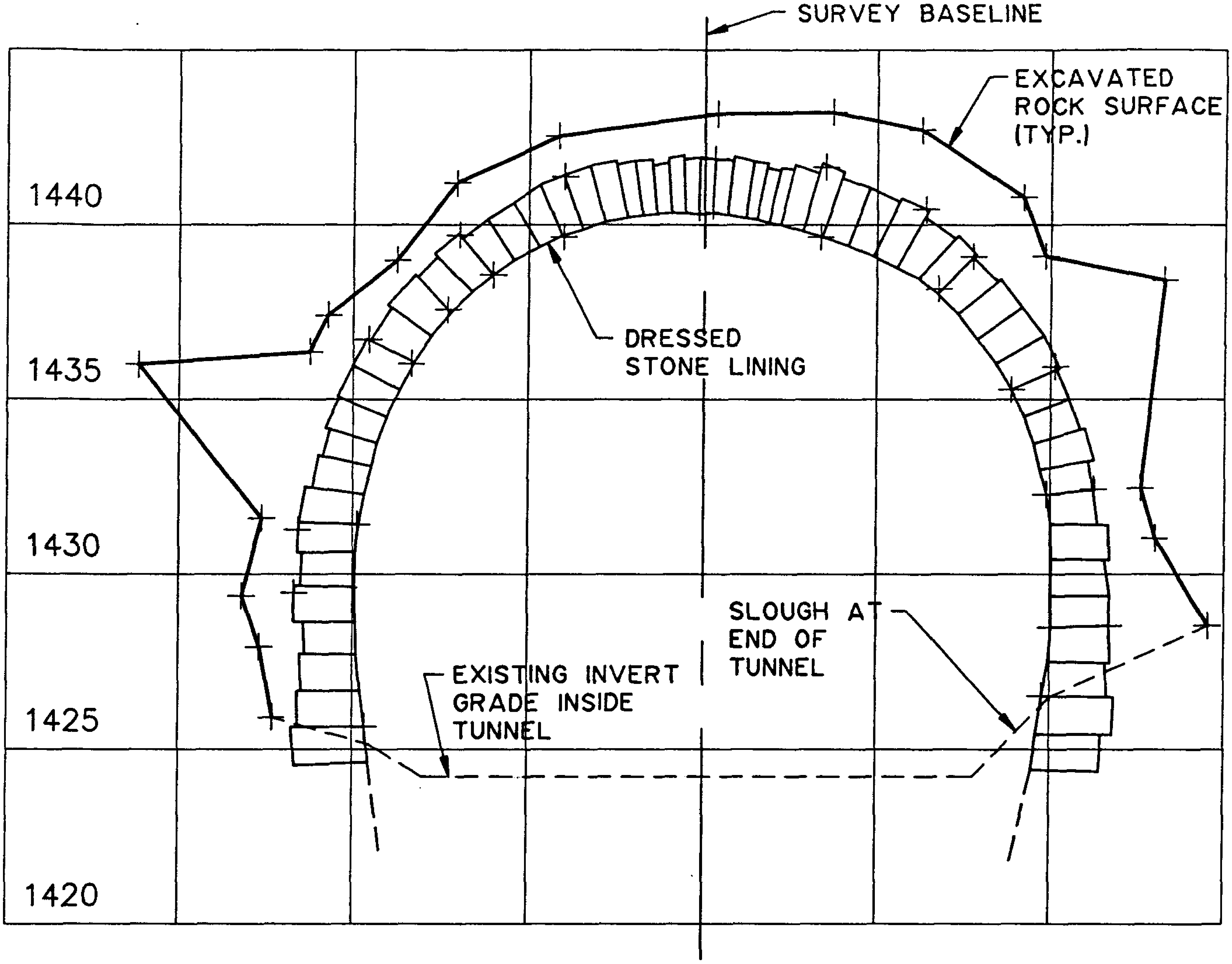
Plotted by Sellards & Grigg, Inc.



CROSS SECTION AT STA. 0+00

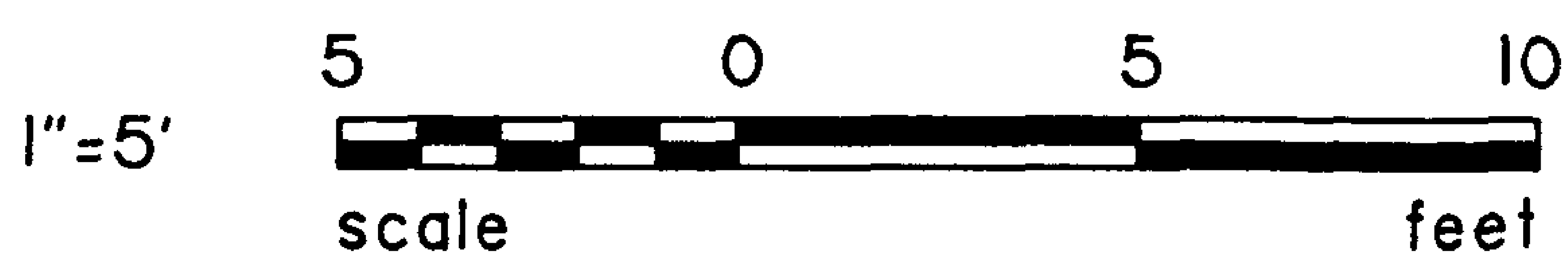
(INSIDE WEST PORTAL)

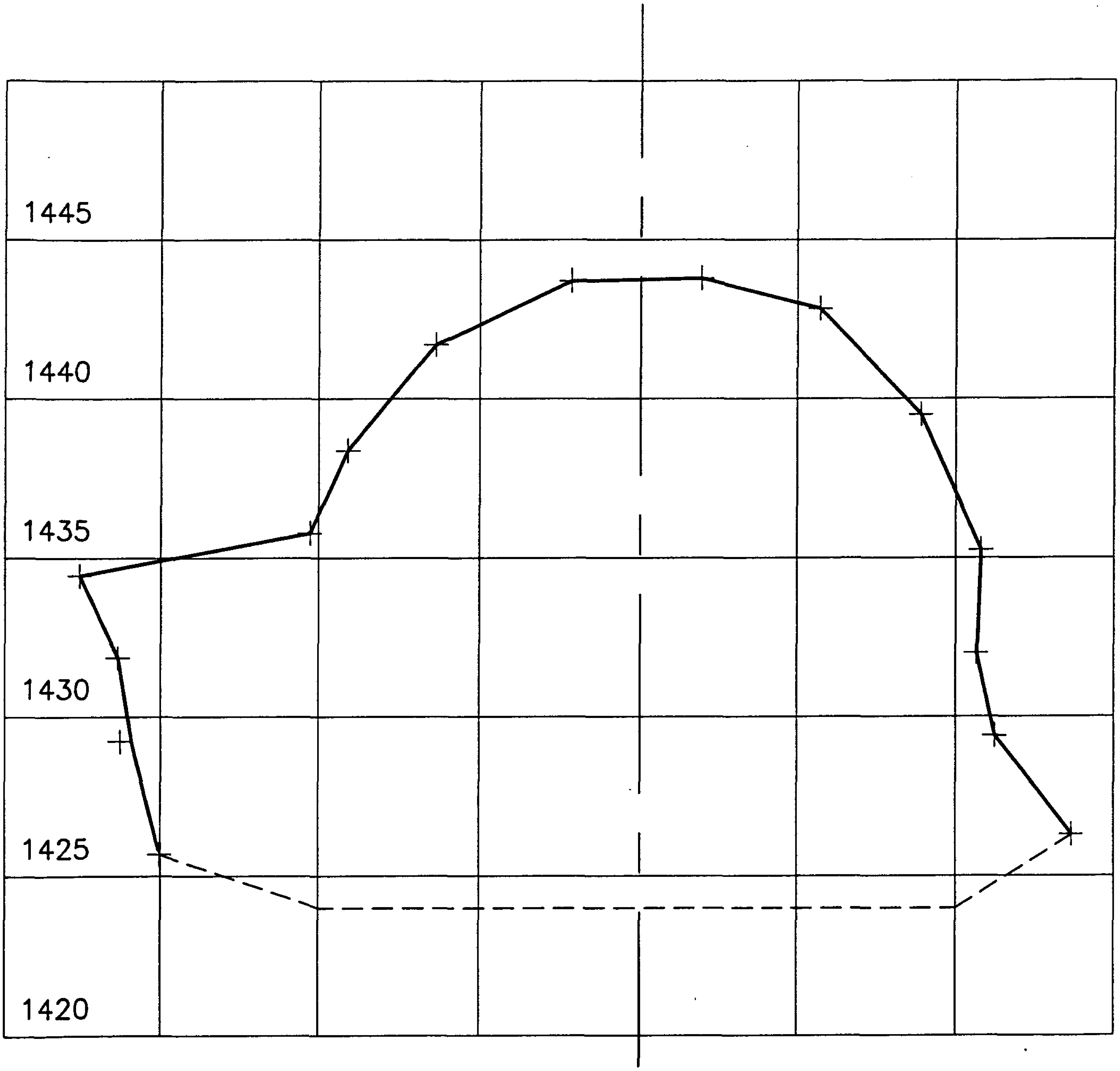




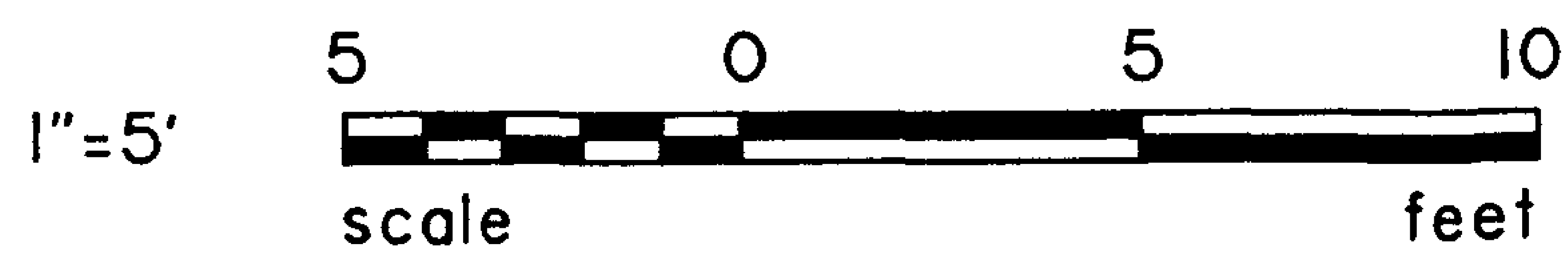
CROSS SECTION AT 1+50

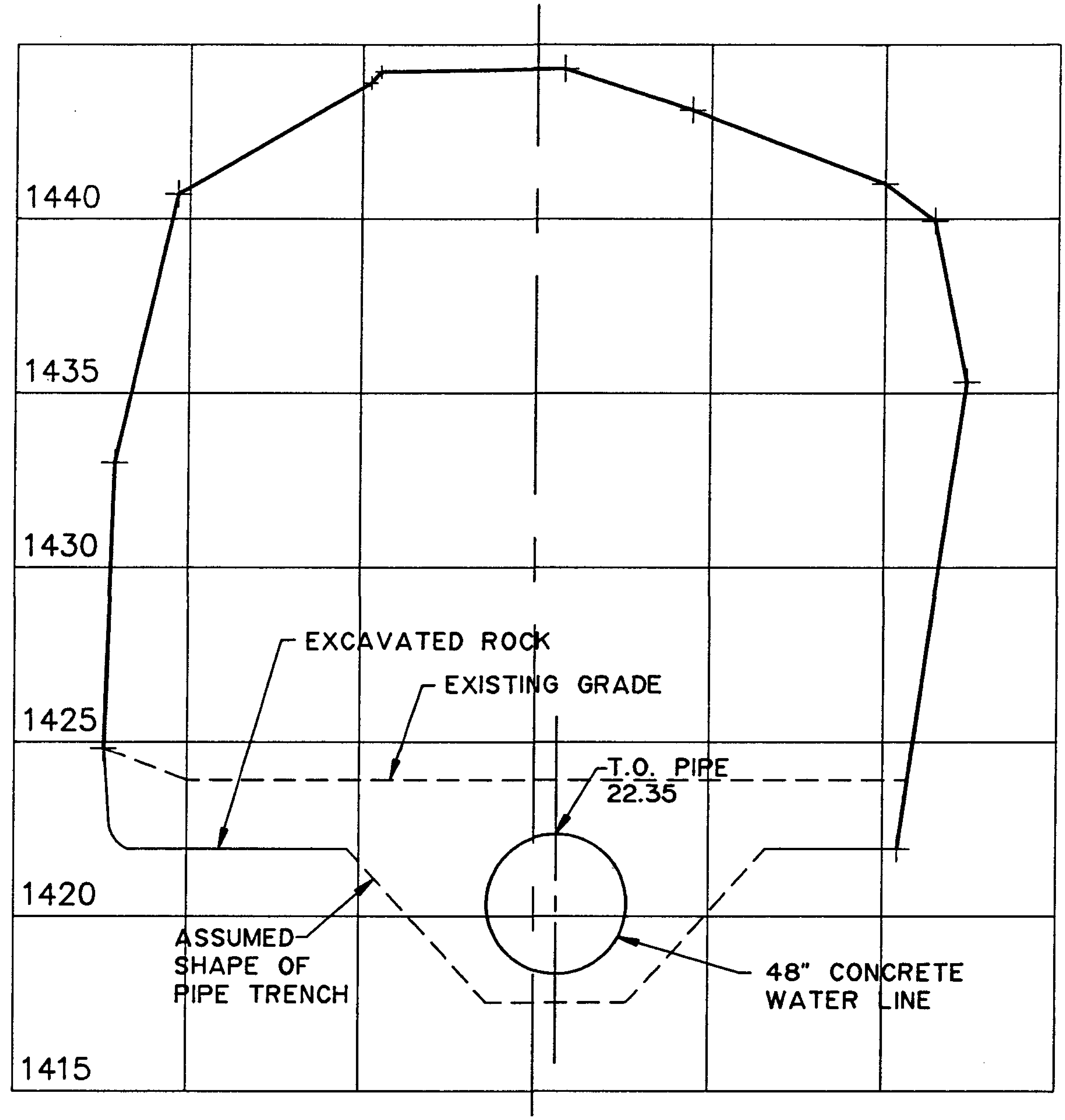
(END OF DRESSED STONE LINING)





CROSS SECTION AT STA. 2+25



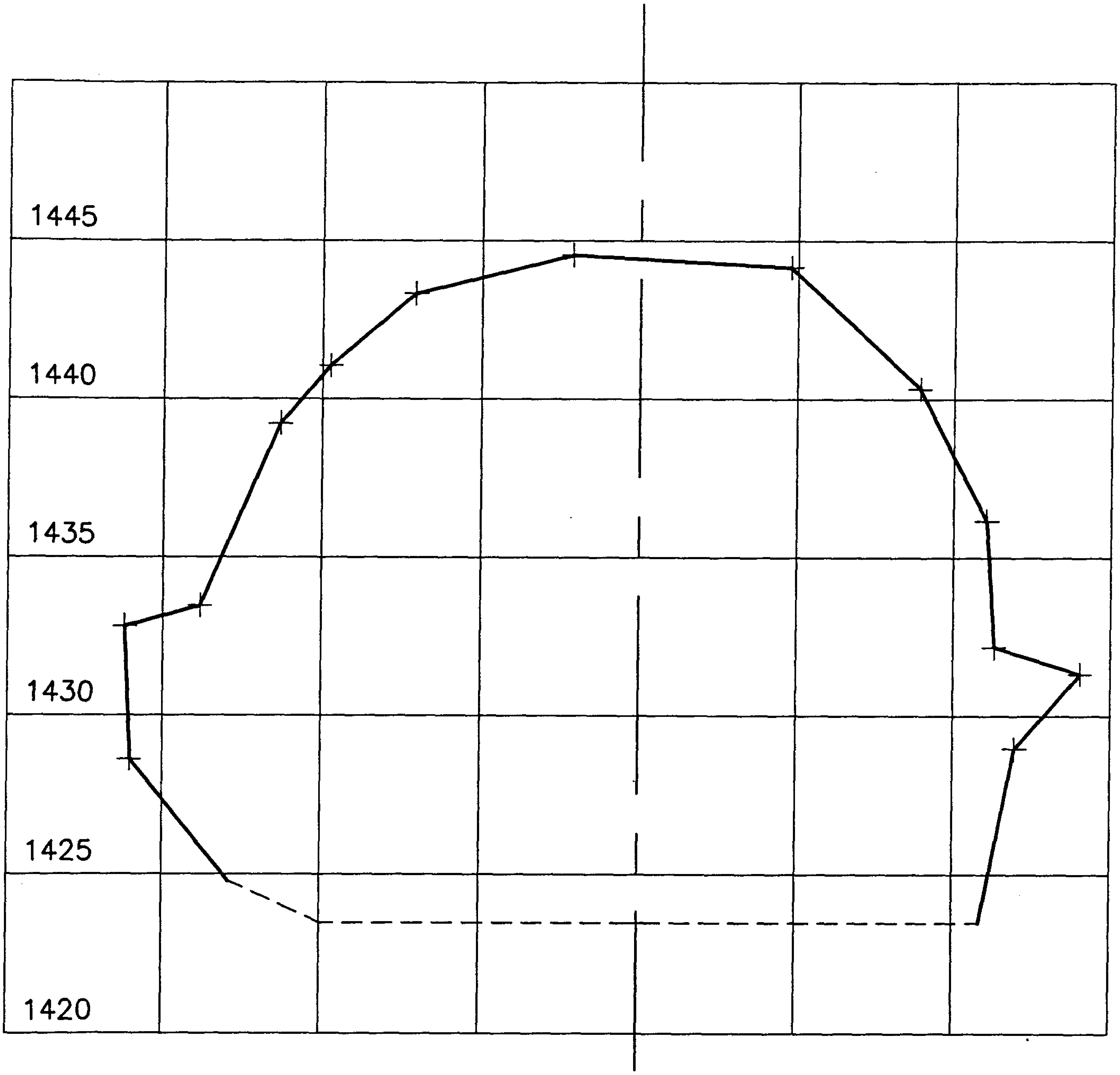


CROSS SECTION AT STA. 3+00

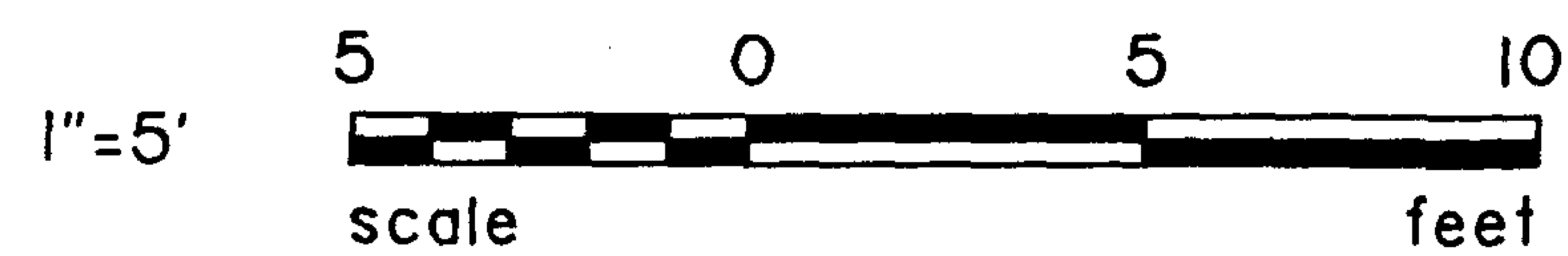
1"=5'

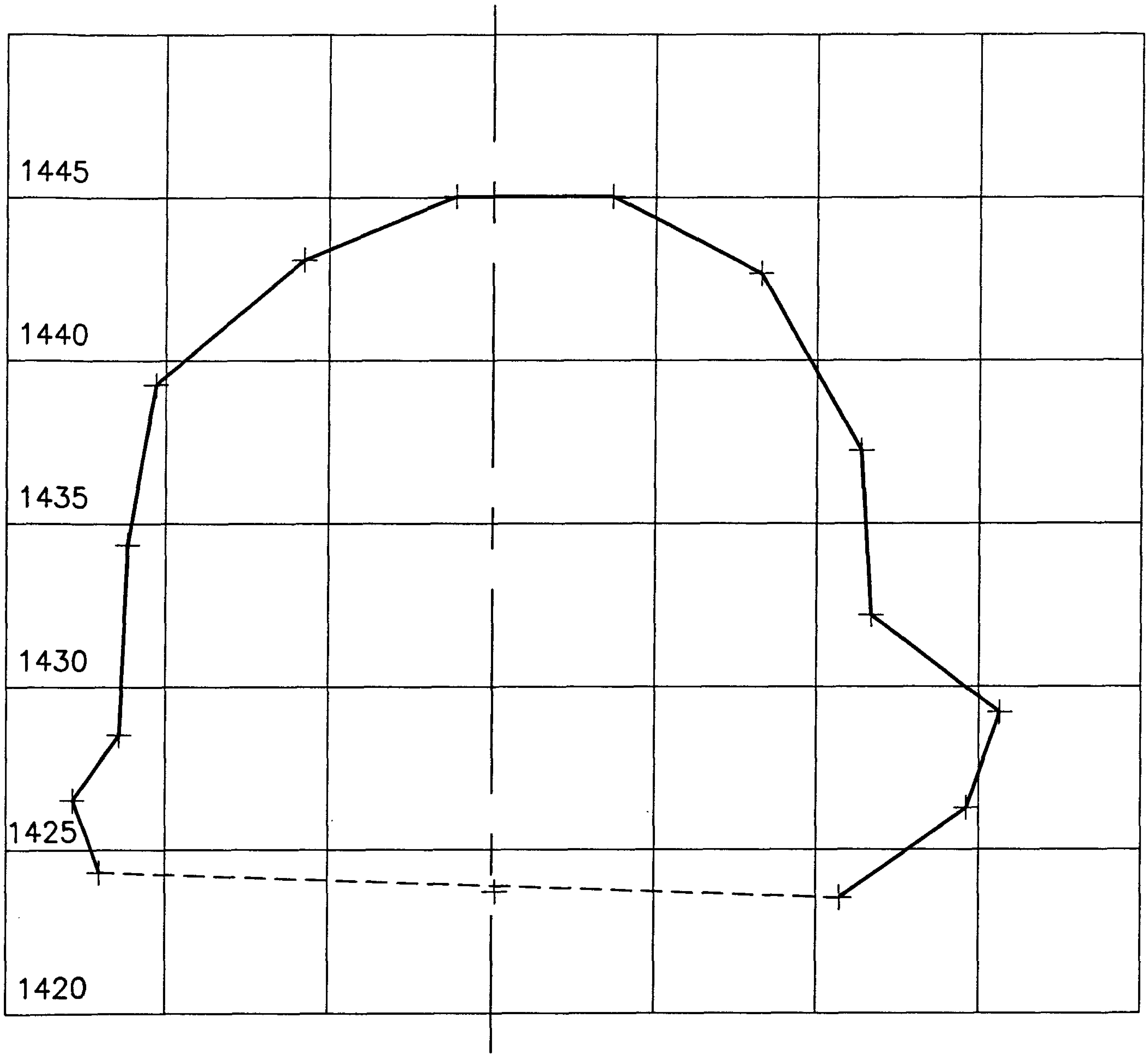
5 0 5 10

scale feet

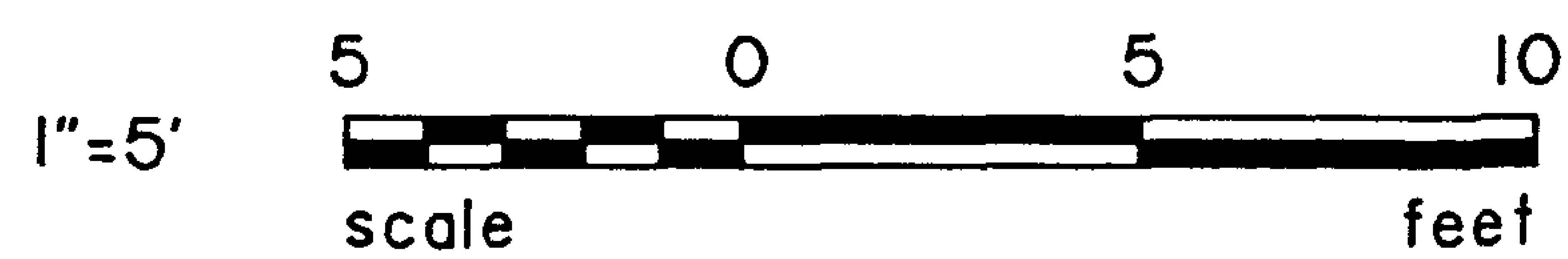


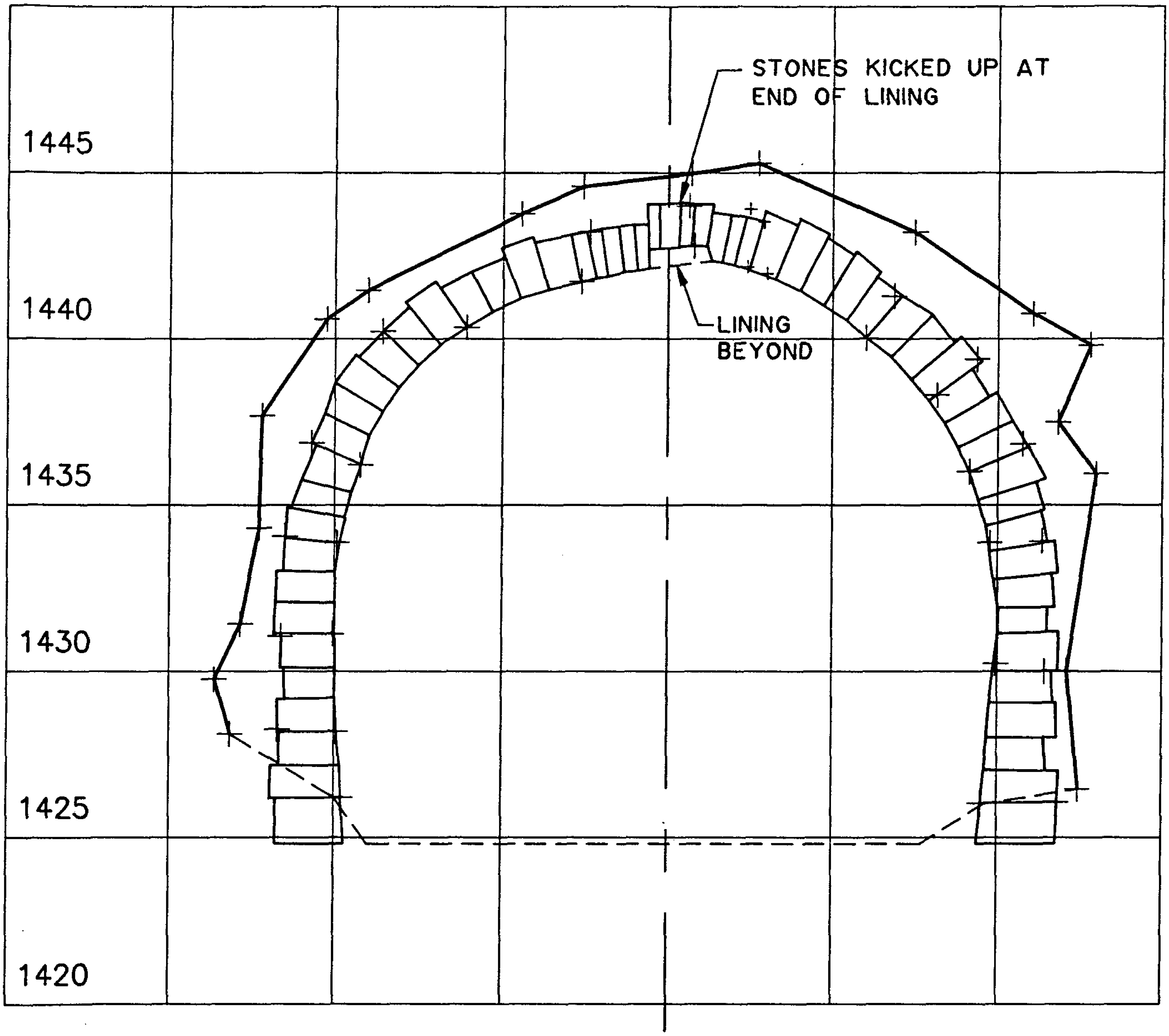
CROSS SECTION AT STA. 4+37





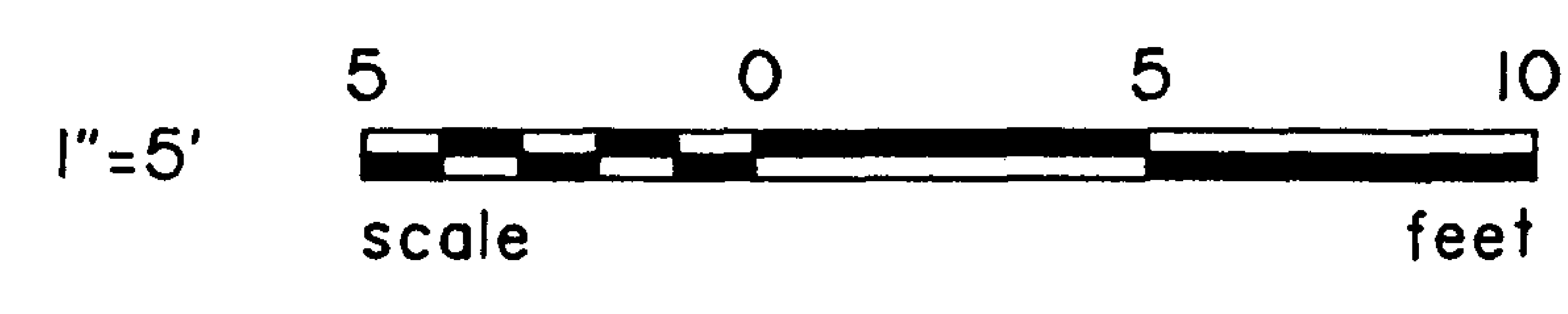
CROSS SECTION AT STA. 6+15

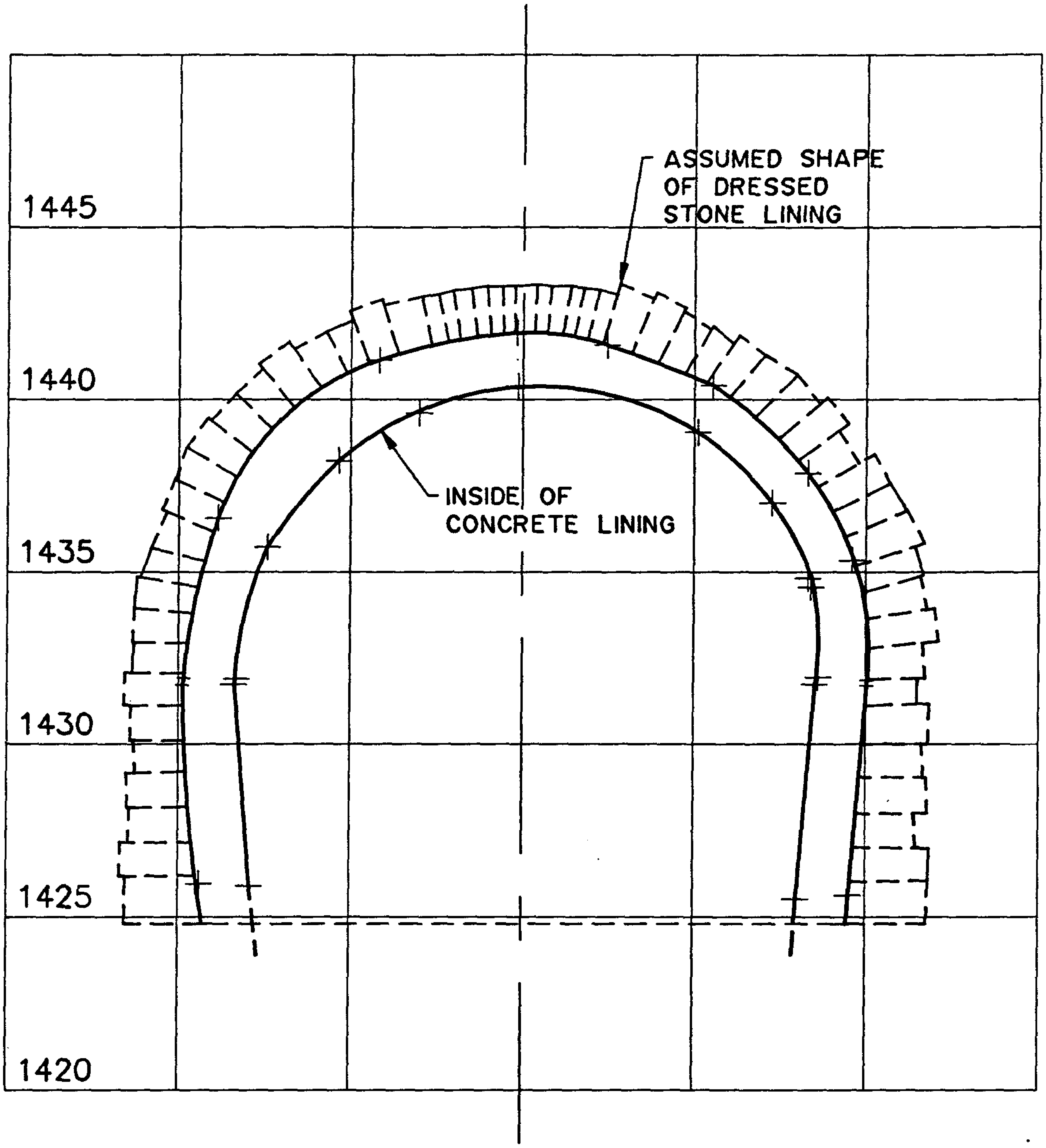




CROSS SECTION AT STA. 7+50

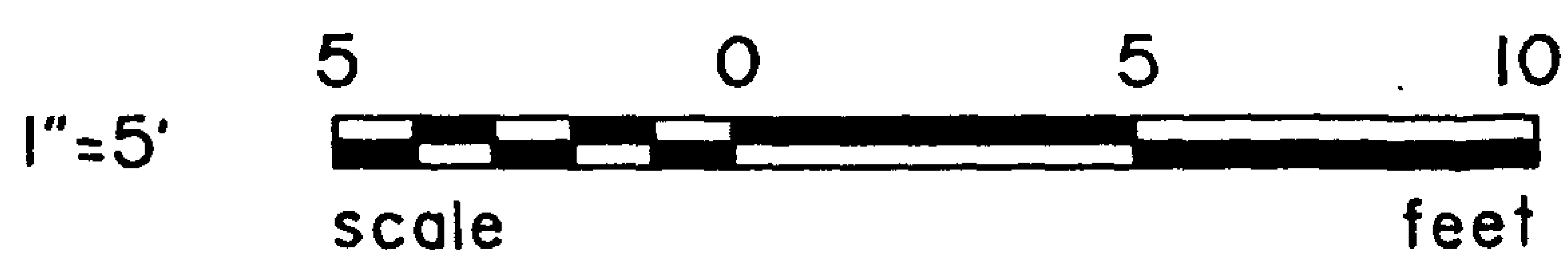
(BEGINNING OF DRESSED STONE LINING)

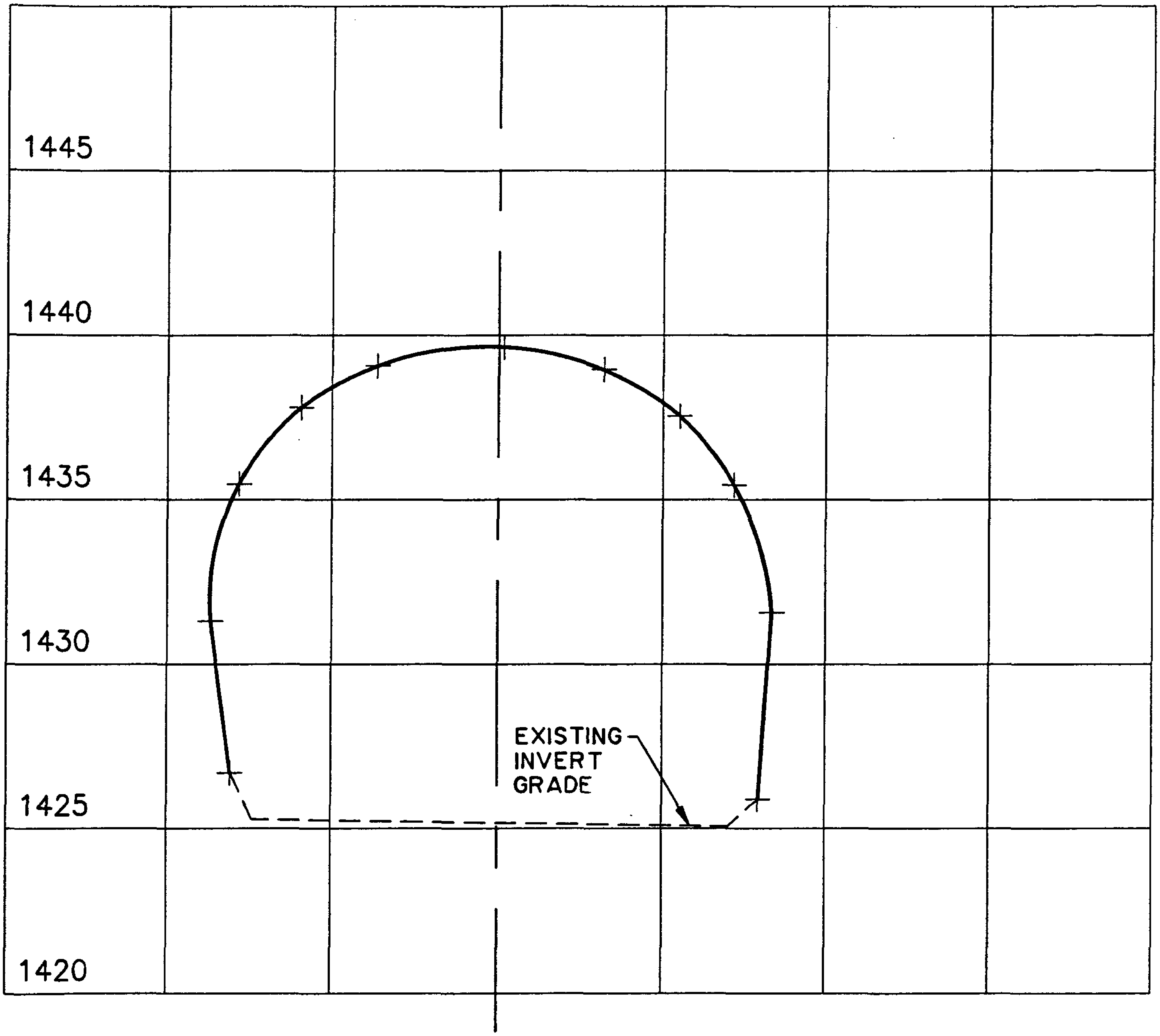




CROSS SECTION AT STA. 8+50

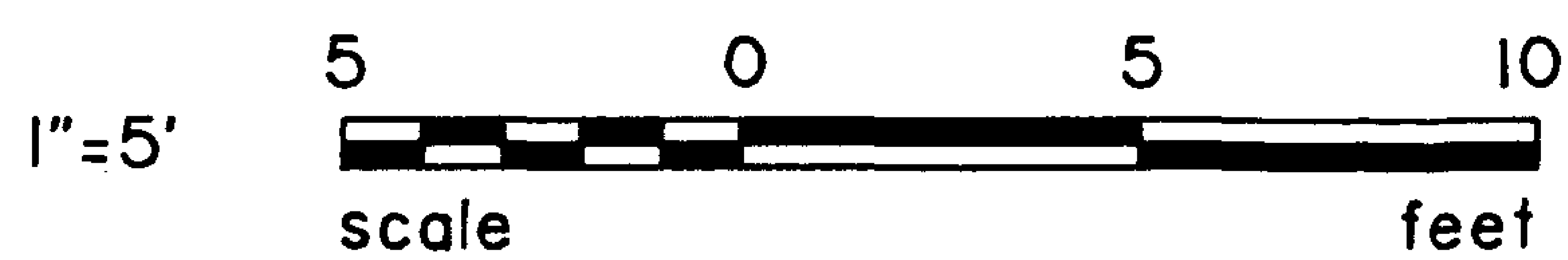
(BEGINNING OF CONCRETE LINING)





CROSS SECTION AT STA. 9+01

(INSIDE EAST PORTAL)




HORIZ. 80 0 80 160
VERT. 5 0 5 10
SCALE OF FEET
GROUND LINE
GROUND LINE
WEST PORTAL FACADE
DRESSED STONE LINING
℄ TUNNEL CROWN (ROUGH CUT ROCK)
DRESSED STONE LINING
POURED CONCRETE LINING
EAST PORTAL
EXISTING GROUND
EXISTING GROUND
℄ OF TUNNEL EXISTING INVERT PROFILE
NOTE: LOCATION OF CROSS-SECTIONS
DIRECTION OF FLOW
48" O.D. CONCRETE WATER LINE
ASSUMED TOP OF WATER LINE PROFILE
0+00
1+50
2+25
3+00
4+38
6+15
7+49
8+50
9+01
1450
1445
1440
1435
1430
1425
1420
1415
1410
0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
ON MICROFILM
DESIGNED: TAY
DRAWN: DTB
TECH. REVIEW: TAY
DATE: 11/26/90
SUB SHEET NO. —
TITLE OF SHEET
EXISTING PROFILE
LOCATION
STAPLE BEND TUNNEL
NEAR MINERAL POINT, PENNSYLVANIA
DRAWING NO. 423 25009
PKG. NO.
SHEET
OF

APPENDIX C

Photographs

August 21-24, 1990

APPENDIX C

PHOTOGRAPHS

Photo No.	Description
1	Test Pit No. 1: Sandstone bedrock foundation for west masonry lining at Sta. 0+59.
2	Test Pit No. 2: 48-inch-outside-diameter concrete water supply line at Sta. 3+00.
3	Test Pit No. 3: Foundation for east masonry lining at Sta. 7+46.
4	Test Pit No. 4: Foundation for concrete and masonry lining at Sta. 8+50.
5	Test Pit No. 5: Foundation for west portal facade at Sta. 0+00.
6	Test Pit No. 6: South face of east portal masonry lining, Sta. 8+95 to Sta. 9+00.
7	Missing arch crown block at Sta. 1+03. Note rubble backfill above masonry lining.
8	Masonry lining at Sta. 7+50. Note annular space between masonry and rock wall.
9	Typical overhang caused by erosion of rusty brown sandstone near Sta. 2+00.
10	Fossil scale tree near Sta. 1+90.
11	Fault with displacement of coal bed near Sta. 6+50.
12	Eroded backfill slope to north of east portal. Note collapsed retaining wall, trees, and remnant of original portal facade (center bottom of photo).

Test Pit No. 1:
Sandstone bedrock foundation for west masonry lining at Sta. 0+59.

Test Pit No. 2:
48 inch outside diameter concrete water supply line at Sta. 3+00.

Test Pit No. 3:
Foundation for east masonry lining at
Sta. 7+46.

Test Pit No. 4:
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lining at Sta. 8+50.

Test Pit No. 5:
Foundation for west portal facade at Sta. 0+00.

Test Pit No. 6:
South face of east portal masonry lining, Sta. 8+95 to Sta. 9+00.

Missing arch crown block at Sta. 1+03.
Note rubble backfill above masonry lining.

Masonry lining at Sta. 7+50.
Note annular space between masonry and rock wall.

Fault with displacement of coal bed near Sta. 6+50.

Eroded backfill slope to north of east portal. Note collapsed retaining wall, trees and remnant of original portal facade (center bottom of photo).

ARCHEOLOGICAL MONITORING OF GEOTECHNICAL TESTS AT STAPLE BEND TUNNEL ALLEGHENY PORTAGE RAILROAD NATIONAL HISTORIC SITE

PACKAGE: ALPO 217B 43

Prepared By:

Karen L. Orrence

Louis Berger & Associates, Inc.
100 Halsted Street
East Orange, New Jersey 07019

Under Contract CX-2000-8-0011
Work Order No. 36

Submitted To:

Eastern Applied Archeology Center
National Park Service
Denver Service Center
11710 Hunters Lane
Rockville, Maryland 20852

February 1991

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

The Staple Bend Tunnel is located approximately five miles north of Johnstown, Pennsylvania (Figure 1). It was constructed as part of the Allegheny Portage Railroad in 1831 (Toogood 1973:57). The tunnel measures 20 feet in width, 19 feet in height, and 901 feet in length. Planned development by the National Park Service (NPS) includes the construction of trails, interpretive exhibits and kiosks, as well as stabilization and possible restoration of the tunnel. A final design has not yet been completed.

Geotechnical testing of the tunnel was monitored by Karen Orrence, an archeologist with Louis Berger & Associates, Inc. (LBA). The purpose of the monitoring was to record any archeological data that would be uncovered by ground disturbing activities associated with the geotechnical tests. The Scope of Services that was prepared by the NPS, Denver Service Center, Eastern Applied Archeology Center, stated that archeological data recovered during monitoring will provide useful information in the planning and design for future stabilization and interpretive programs involving Staple Bend Tunnel. In addition, monitoring will insure that any impacts on archeological resources incidental of geotechnical testing will be archeologically mitigated.

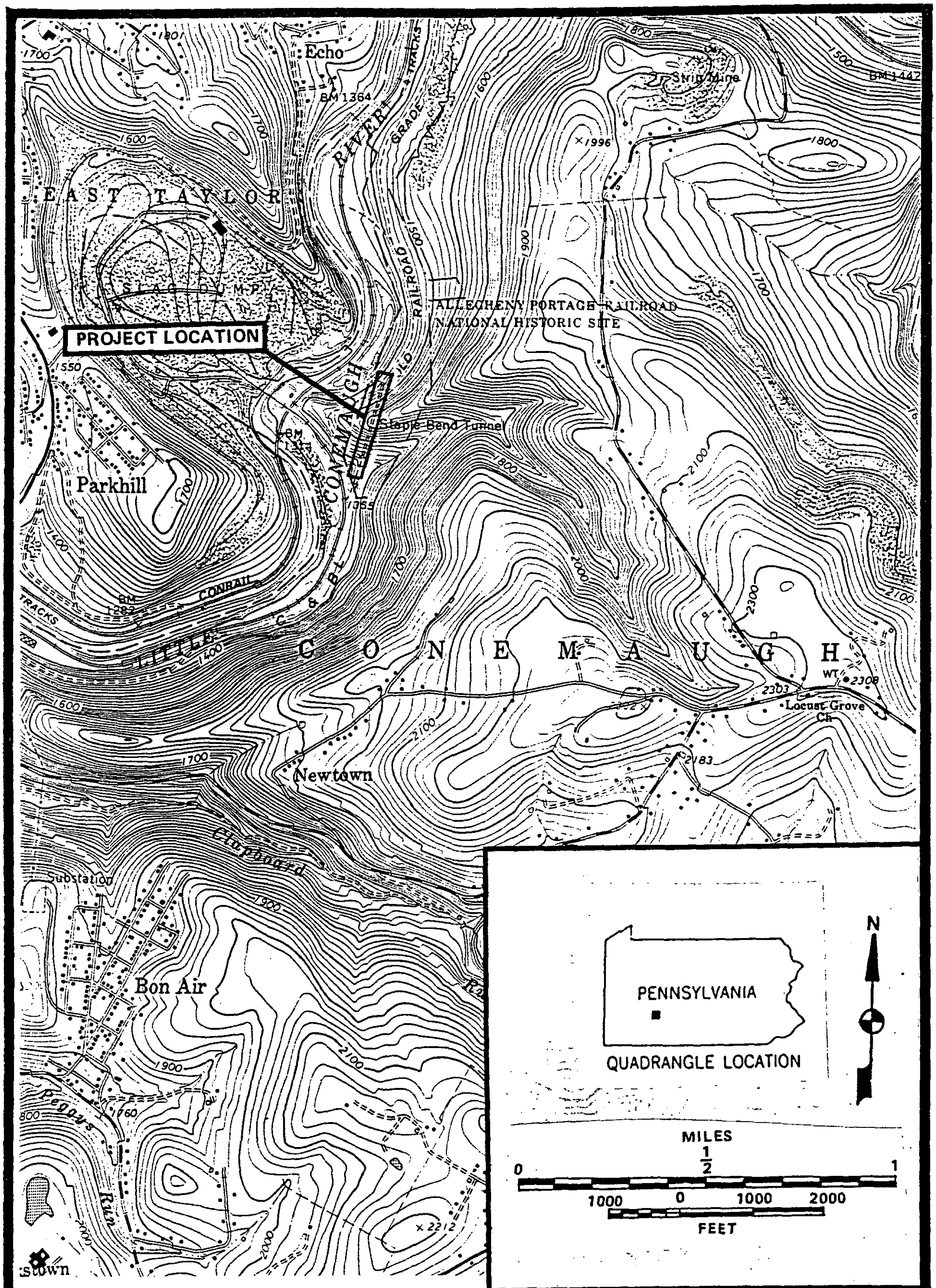


FIGURE 1 Vicinity Map

SOURCE : USGS 7.5 Minute Series, Geistown, Pa. 1964, photorevised 1981

II. DESCRIPTION OF FIELDWORK

A. INTRODUCTION

Fieldwork was conducted between August 20 and 24, 1990. All cultural resources exposed were documented with measured drawings (plans and profiles), photographs, and field notes. Soils were described by texture, according to USDA classifications, and Munsell soil color. Photographs were taken where appropriate. Artifacts were not collected, but identified and noted in the field.

The number and placement of the hand-excavated test pits was determined by the Denver Service Center and the contractors conducting the geophysical investigations (GEI Consultants, Inc./ Sellards & Grigg). The exact location of the six tests will be shown on a map being prepared by the geophysical consultants. Figure 2 is a schematic (not to scale) that shows the approximate location of each test. The dimension, location, and purpose of each test unit are summarized below.

Test Unit 1 was a 3.5-by-4 foot unit placed adjacent to the dressed stone liner along the south wall of the tunnel, near the western portal. This test was excavated to locate the base of the stone liner.

Test Unit 2 was a 3-by-24 foot unit excavated across the width of the tunnel to define the location and the method of placing the 48-inch-diameter water pipe that runs through the tunnel. This pipe was installed by Bethlehem Steel in the 1930s or 1940s.

Test Unit 3, a 3-by-5 foot unit, was excavated adjacent to the end of the dressed stone liner along the south wall of the tunnel near the eastern portal. The purpose of this unit was to gain architectural/engineering data on the depth of the dressed stone liner, its method of construction, and its relationship to the tunnel wall and floor.

Test Unit 4 was a 4-by-4 foot test excavated at the end of the masonry liner along the south wall of the tunnel near the eastern portal. This unit was excavated to gain architectural/engineering data on the construction of the masonry liner and its relationship to the dressed stone liner and tunnel.

Test Unit 5, a 2.5-by-5 foot unit, was placed outside of the tunnel adjacent to the facade of the West Portal. This test was excavated to locate the base of the portal facade.

Test Unit 6 was excavated at the East Portal to expose the top of the tunnel and the dressed stone liner. This test roughly measured

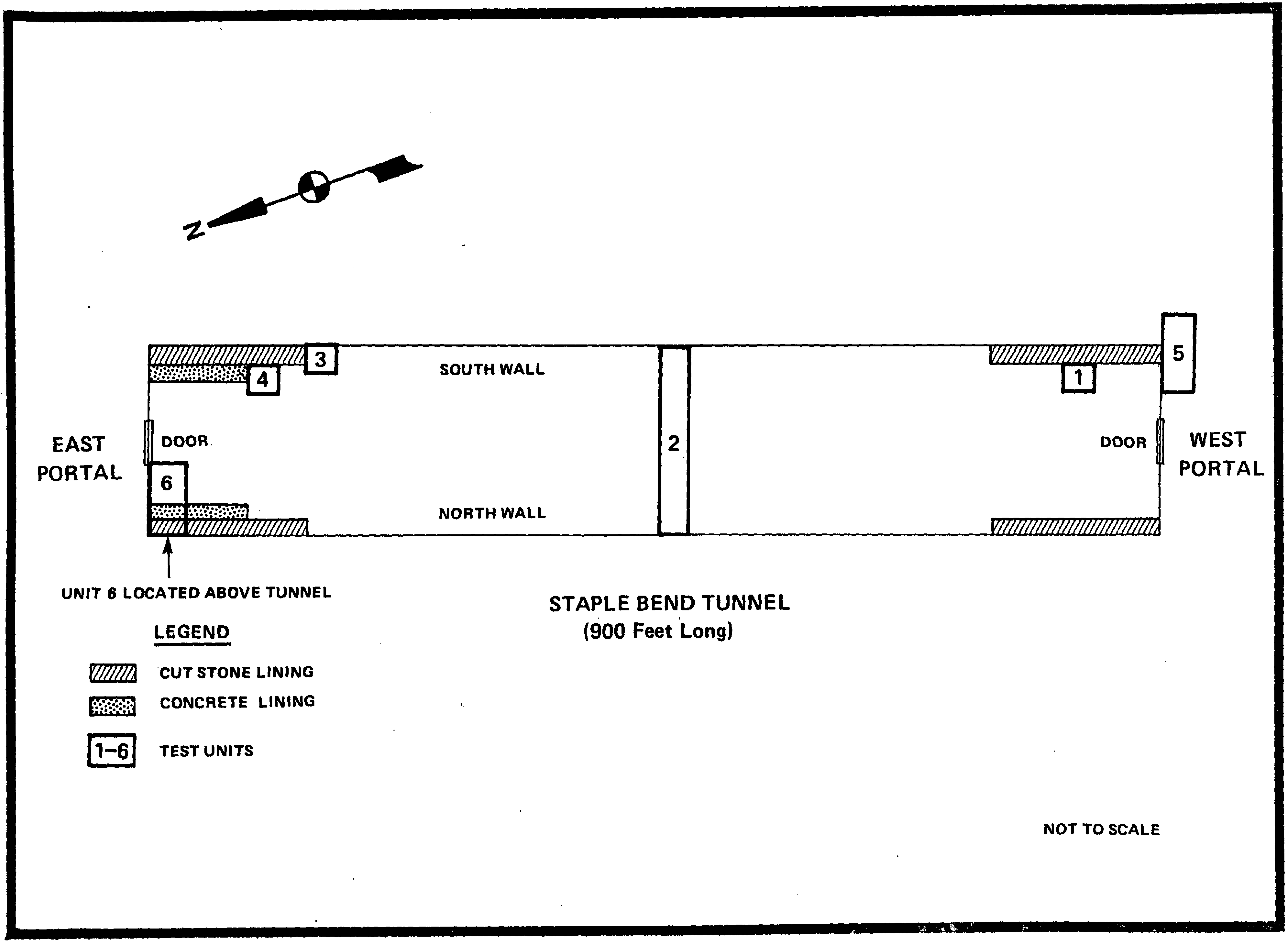


FIGURE 2 Approximate Location of Geophysical Tests

5.5-by-9 feet. This test was excavated to reveal why the east end of the tunnel has shifted.

B. TEST UNIT DESCRIPTIONS

Test Unit 1 was excavated around an area that had subsided to a depth of about one foot. The cause of this erosion was not determined. The unit was excavated to a depth of four feet below present ground surface (Figure 3). Only one soil stratum was observed, a 10YR 5/1 gray silty clay mottled with a 10YR 7/6 yellow clay. These were very wet, dense clays that contained a few small sandstone fragments. This thick deposit of fill was also found in Test Unit 4 around the masonry liner footing. The masonry liner was probably installed by Bethlehem Steel around the same time as the concrete water pipe.

Three additional courses of the dressed stone liner were exposed in this unit. The base of the dressed liner rests directly upon sandstone bedrock. The original floor of the tunnel was encountered 3.5 feet below present ground surface. The floor was composed of sandstone bedrock. Two wire nails were noted in this test unit, but not collected. No other artifacts or evidence of the track were found.

Test Unit 2 was a trench excavated across the width of the tunnel. The tunnel was 24 feet wide at this location. At the south end of the trench, the bedrock floor of the tunnel was encountered 2.3 feet below present ground surface. The bedrock tunnel floor ends approximately 4 feet from the south wall of the tunnel. At this point, the bedrock floor was excavated deeper to install the 48-inch concrete water pipe. The top of the pipe was 1.5 feet below present ground surface.

Eleven soil strata were recorded in Test Unit 2 (Figure 4). The utility trench excavated for the concrete water pipe contained two strata, A and K. The backfill from the utility trench was spread the entire width of the tunnel. Stratum A was the first strata in the utility trench. It was a mixture of 10YR 4/1 dark gray, 10YR 4/2 dark grayish brown, and 10YR 4/3 brown/dark brown silty clay loam with large mottles of 10YR 6/2 light brownish gray silty clay and 2.5Y 6/6 olive green clay. Several board fragments were found in this stratum on the north side of the concrete pipe. These boards were not found in situ. The boards smelled of creosote and were probably the remains of an earlier wooden stave water pipe installed by Bethlehem Steel. A section of this wooden water pipe was discovered during archeological testing of Level 1 in 1989 (Holt and Alterman 1990). Stratum K, the second stratum in the utility trench, was found on the north side of the concrete water pipe. It was a 5YR 4/2 reddish gray silty loam with sandstone fragments and decayed boards. The reddish color was caused by the large amount of decayed wood in the soil.

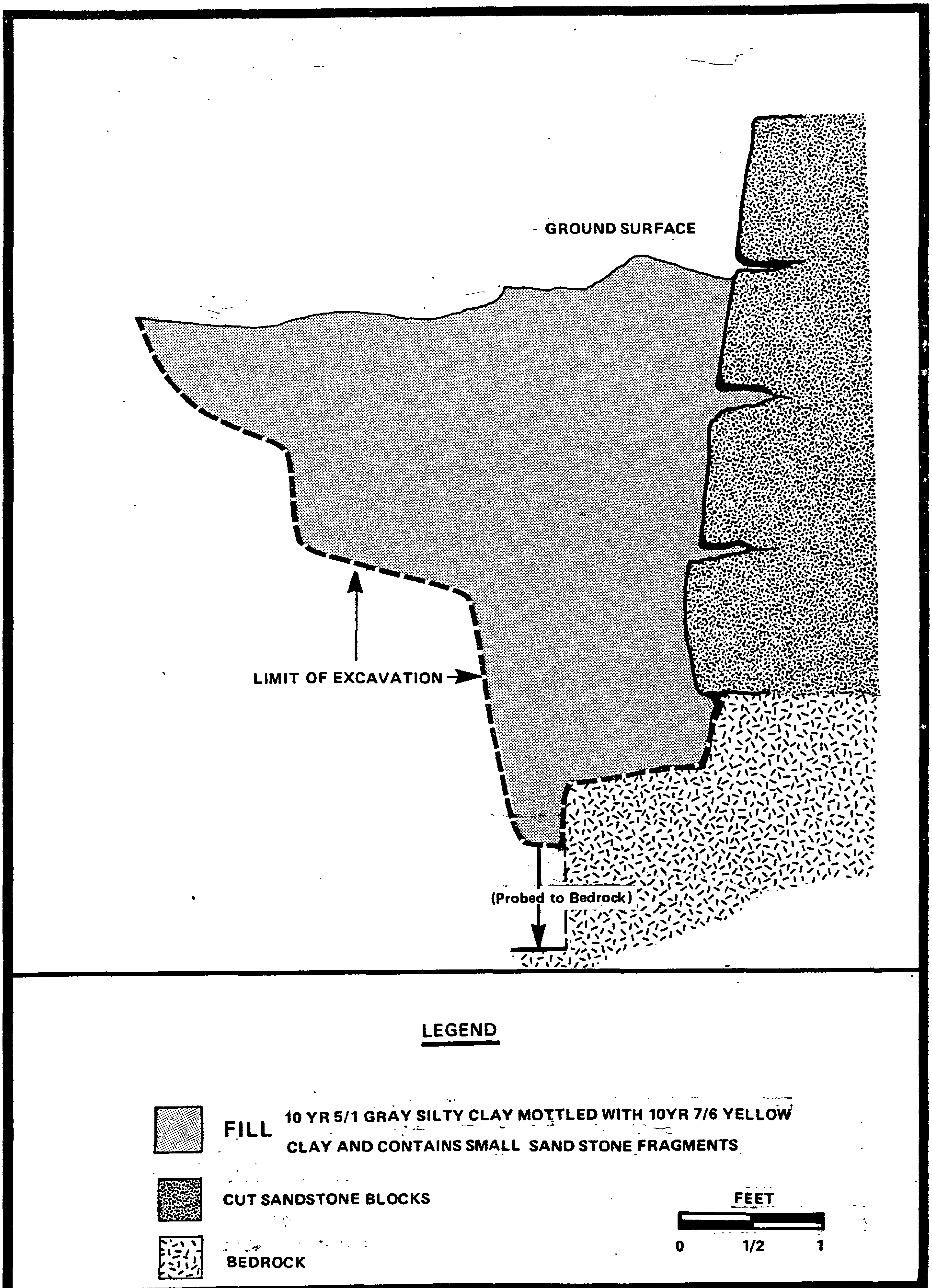


FIGURE 3 Test Unit 1, North Profile

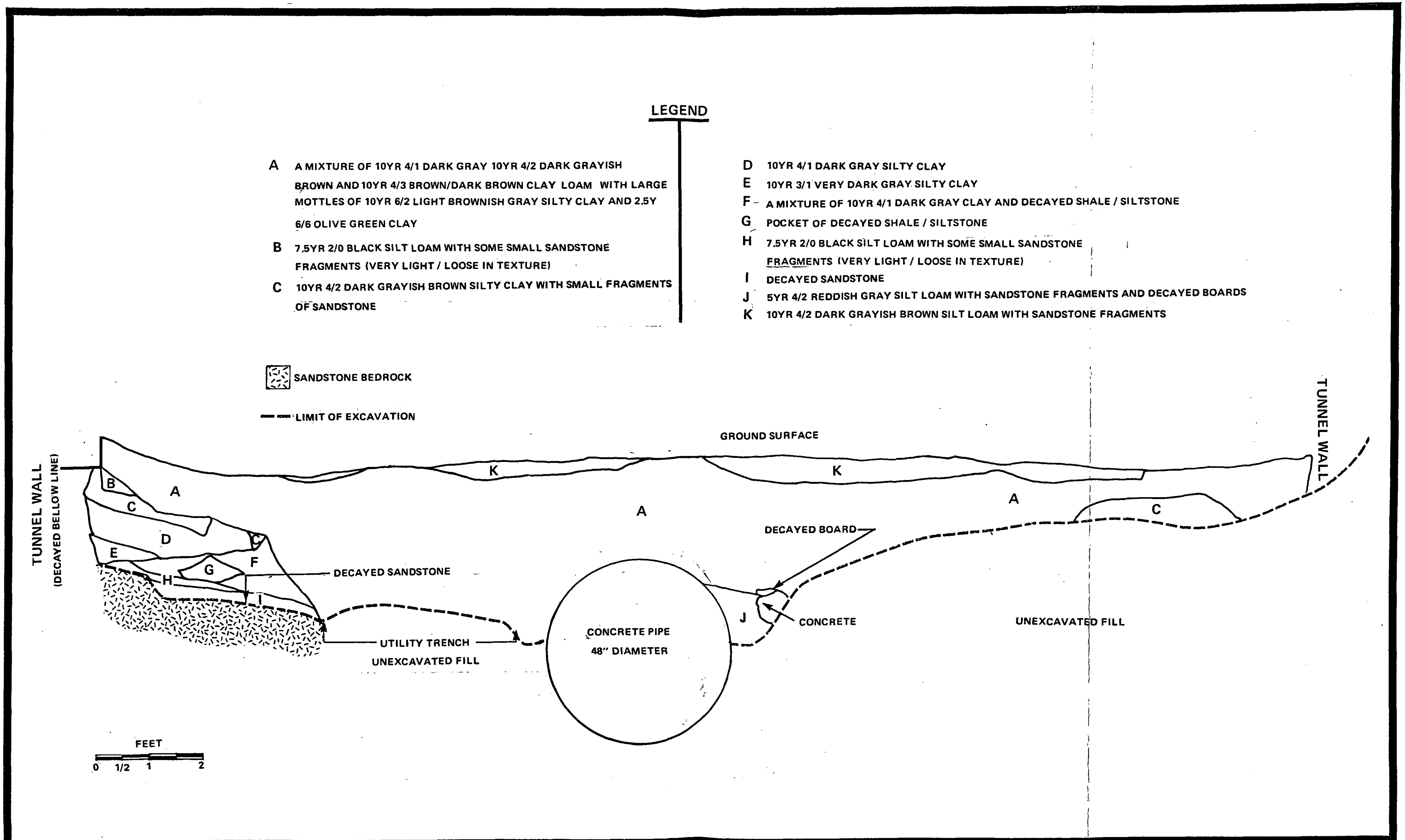


FIGURE 4 Test Unit 2, South Profile

Eight strata could be seen under the utility backfill at the south end of the trench. All of the strata appear to be rockfall deposits. No artifacts were found in any of these strata. Stratum B was a 7.5YR 2/0 black silt loam with some sandstone fragments. It was very light/loose in texture. This same soil was found near the base of the unit, in Stratum H. It was also found in two other excavation units, Stratum B in Test Units 3 and 6. Stratum C was a 10YR 4/2 dark grayish brown silty clay with small fragments of sandstone. This same deposit was found beneath the utility backfill at the north end of the trench. Stratum C in Test Unit 6 was also this soil color and texture. Stratum D was a 10YR 4/1 dark gray decayed shale. This shale was found in Test Units 3 and 4 as well. It was called Stratum C in Test Unit 3 and Stratum A in Test Unit 4. Stratum E was a small pocket of 10YR 3/1 very dark gray silty clay. Stratum F was a mixture of 10YR 4/1 dark gray clay and decayed shale. Stratum G was a pocket of decayed shale found within Stratum F. Stratum I was a thin layer of decayed sandstone. This was the decaying top layer of the tunnel floor. Beneath this stratum was the solid bedrock floor of the tunnel. Stratum L was found in patches across the top surface of the present ground surface. It was a 10YR 4/2 dark grayish brown silt loam with sandstone fragments. This recent deposit was called Stratum G in Test Unit 3 and could be seen throughout the length of the tunnel.

Test Unit 3 was excavated at the east portal end of the tunnel adjacent to the end of the dressed stone liner. The dressed stones step-out in a quoin-fashion (Figure 5). The base of the dressed stones rest upon siltstone bedrock 1.6 feet below present ground surface. The floor of the tunnel was located 2 feet below present ground surface.

The soil stratigraphy in Test Unit 3 was very similar to that in Test Unit 2 (Figure 6). Strata A, B, C, and G were the same soils as found in Test Unit 2 and have already been described. Stratum D was a pocket of 10YR 5/6 yellowish brown shale found within Stratum C. Stratum E was a 10YR 5/3 brown shale deposit found above the siltstone bedrock floor of the tunnel at the south end of the unit. At the north end of the unit, Stratum F appears above the siltstone bedrock floor. Stratum F was a 10YR 3/1 very dark gray, gritty, decayed shale which contained artifacts. A thin, green-tinted window glass fragment and one badly-corroded railroad spike were found in this stratum.

Several other artifacts were found in this unit. These artifacts were found in the backdirt and have no provenience. They probably came from Stratum F. They include one rail chair, two iron wire fragments, one iron spike, one large iron bolt with square nut attached, and a board fragment.

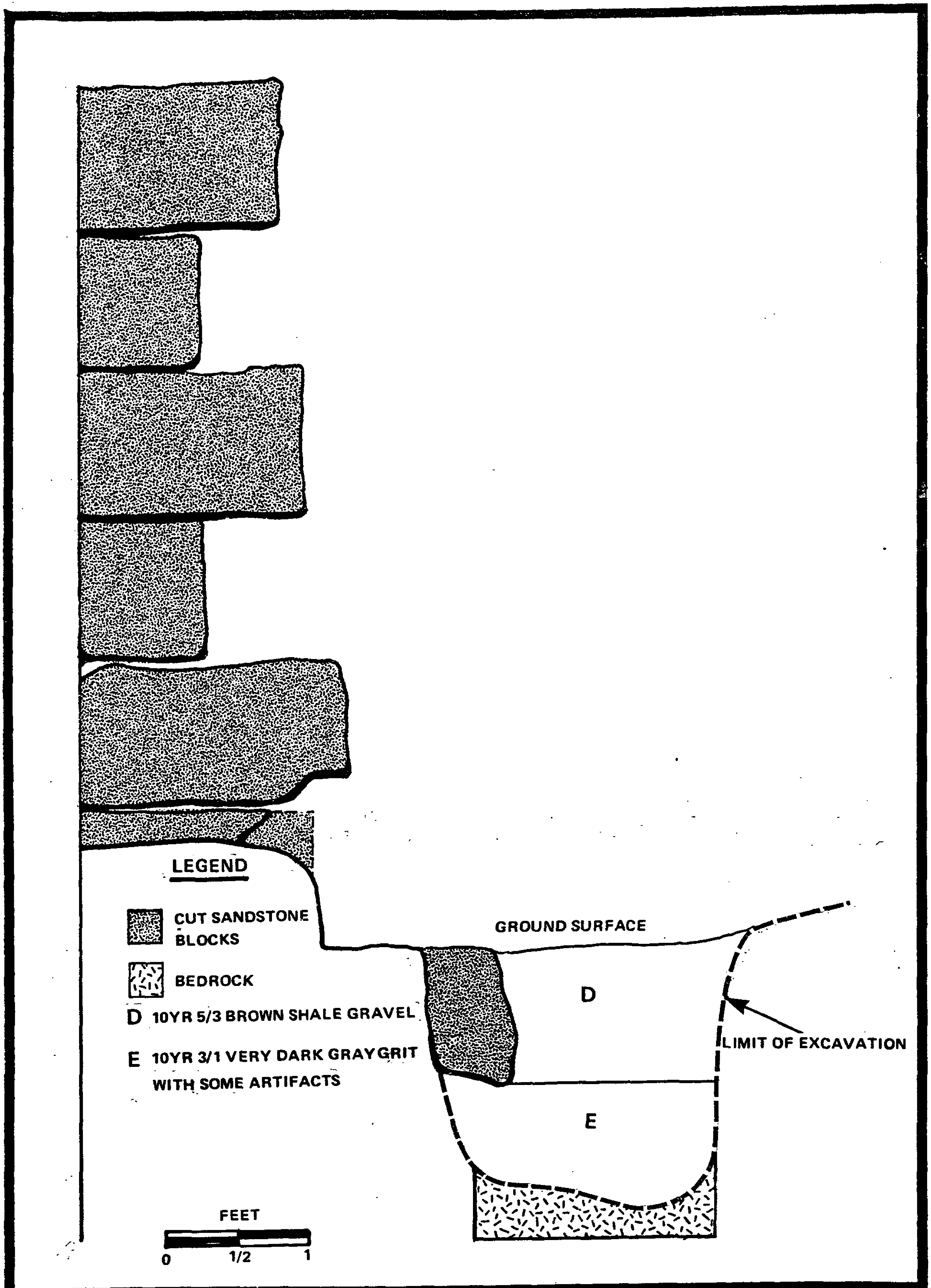
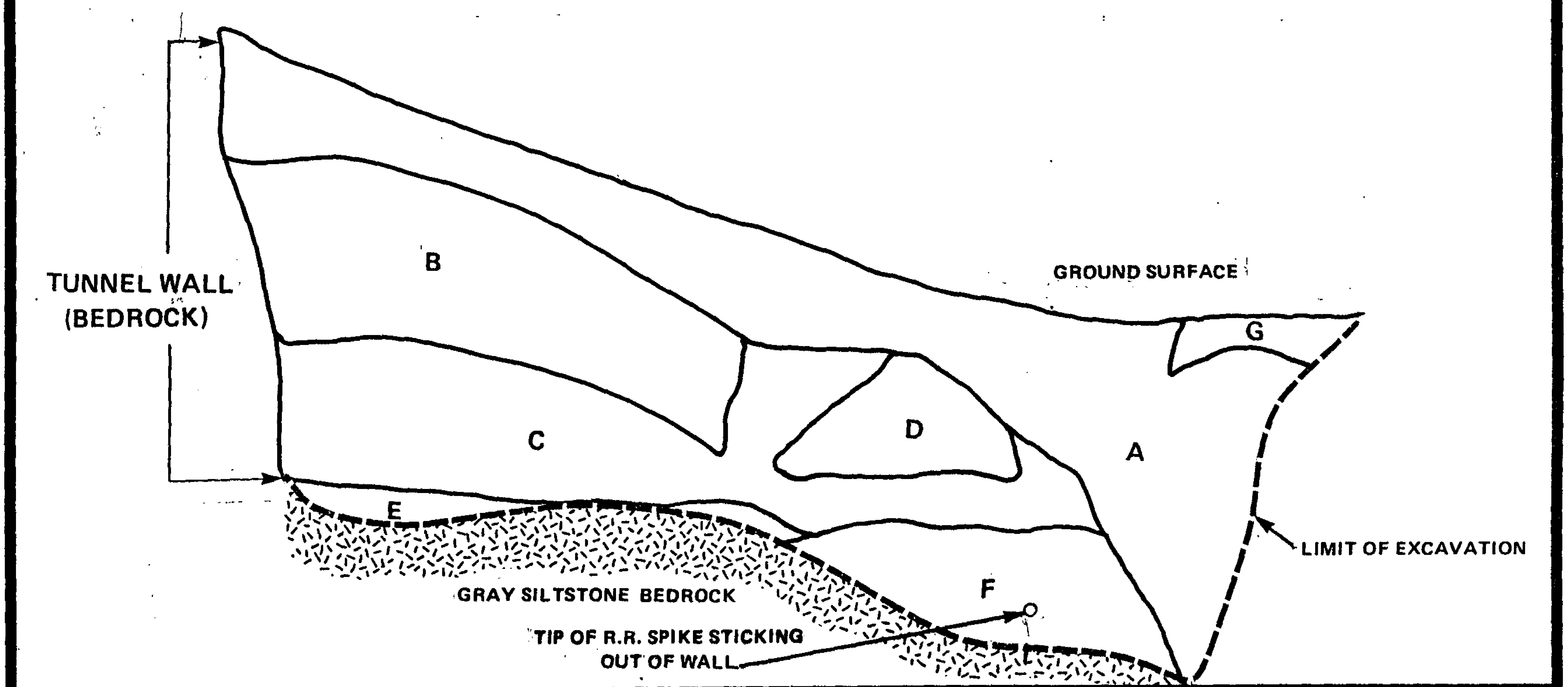


FIGURE 5 Test Unit 3, Cross Section



LEGEND

- A — A MIXTURE OF 10YR 4/1 DARK GRAY, 10YR 4/2 DARK GRAYISH BROWN AND 10YR 4/3 DARK BROWN CLAY LOAM WITH LARGE MOTTLES OF 10YR 6/2 LIGHT BROWNISH GRAY SILTY CLAY AND 2.5Y 6/6 OLIVE GREEN CLAY
- B — 7.5YR 2/0 BLACK SILTY LOAM WITH SOME SMALL SANDSTONE FRAGMENTS
- C — 10YR 4/1 DARK GRAY DECAYED SHALE
- D — SAME AS C ABOVE BUT WITH MORE SHALE FRAGMENTS WHICH APPEAR 10YR 5/6 YELLOWISH BROWN IN COLOR
- E — 10YR 5/3 BROWN SHALE
- F — 10YR 3/1 GRITTY DECAYED SHALE
- G — 10YR 4/2 DARK GRAYISH BROWN SILT LOAM WITH SANDSTONE FRAGMENTS

FEET
0 1/2 1

FIGURE 6 Test Unit 3, South Profile

Test Unit 4 was excavated at the east portal end of the tunnel, adjacent to the end of the masonry liner. The masonry liner was composed of concrete. A concrete footer for the liner was uncovered in the test unit (Figure 7). The footer extended 4.5 feet west and 1.5 feet north of the liner, and was 1.05 feet thick. An architectural feature, a keyway, was found on the top surface of the footer. The keyway indicated that the footer was poured separately from the liner. The masonry liner was not tied into the dressed stone liner, but butted up against it.

Test Unit 4 contained only two strata, both of which were found in other test units (Figure 8). Stratum A, a 10YR 4/1 dark gray decayed shale, was also found in Tests Units 2 and 3. Stratum B was the same 10YR 5/1 gray silty clay mottled with 10YR 7/6 yellow clay found in Test Unit 1. Standing water was encountered 1.3 feet below present ground surface. No artifacts were found.

Test Unit 5 was excavated outside of the tunnel, adjacent to the west portal facade. The base of the facade was located 4 feet below present ground surface (Figure 9). The stone facade rests upon sandstone bedrock. Six soil strata were found. Strata A and B were slope erosion deposits washed down from the hillside above. Stratum A was a mixture of 10YR 5/1 gray silty clay, 10YR 6/4 light yellowish brown stiff clay, and 10YR 3/1 very dark gray broken shale fragments. Stratum B was a mixture of 10YR 3/1 very dark gray broken shale fragments and 10YR 2/1 black silt. Stratum C appears to be a buried A-horizon. It was a 10YR 3/1 very dark gray silty loam, very organic in texture. Strata D, E, and F appear to be historic deposits. Stratum D was a 7.5YR 5/4 fine sand containing very decayed brick fragments. This may be the remains of a brick paving between the tunnel and Engine House 1. Stratum E was a 10YR 4/2 dark grayish brown silty clay which contained no rock fragments. A corroded iron fragment could be seen in this stratum. Stratum F was a 10YR 5/3 brown silty clay with mottles of 10YR 5/4 brown silty clay and very small fragments of sandstone. No artifacts were recovered from this stratum. Beneath Stratum F was sandstone bedrock.

Several artifacts were found in Test Unit 5 during excavation. These have no strata provenience. They included one wrought iron, wedge-shaped bar, possibly a pick fragment; one thick, blue-tinted bottle glass body fragment with no mold marks and many small air bubbles; one redware rim fragment with a clear lead-glazed interior, unglazed exterior; one unidentified molded iron fragment; three unidentified strap iron fragments; and several brick fragments.

Test Unit 6 was excavated on top of the tunnel, at the east portal end. This unit was excavated to expose the stone liner and determine why it has shifted. A representative profile was taken at the base of the excavation unit (Figure 10). Three soil strata were exposed. Stratum A was a 10YR 3/2 very dark grayish brown

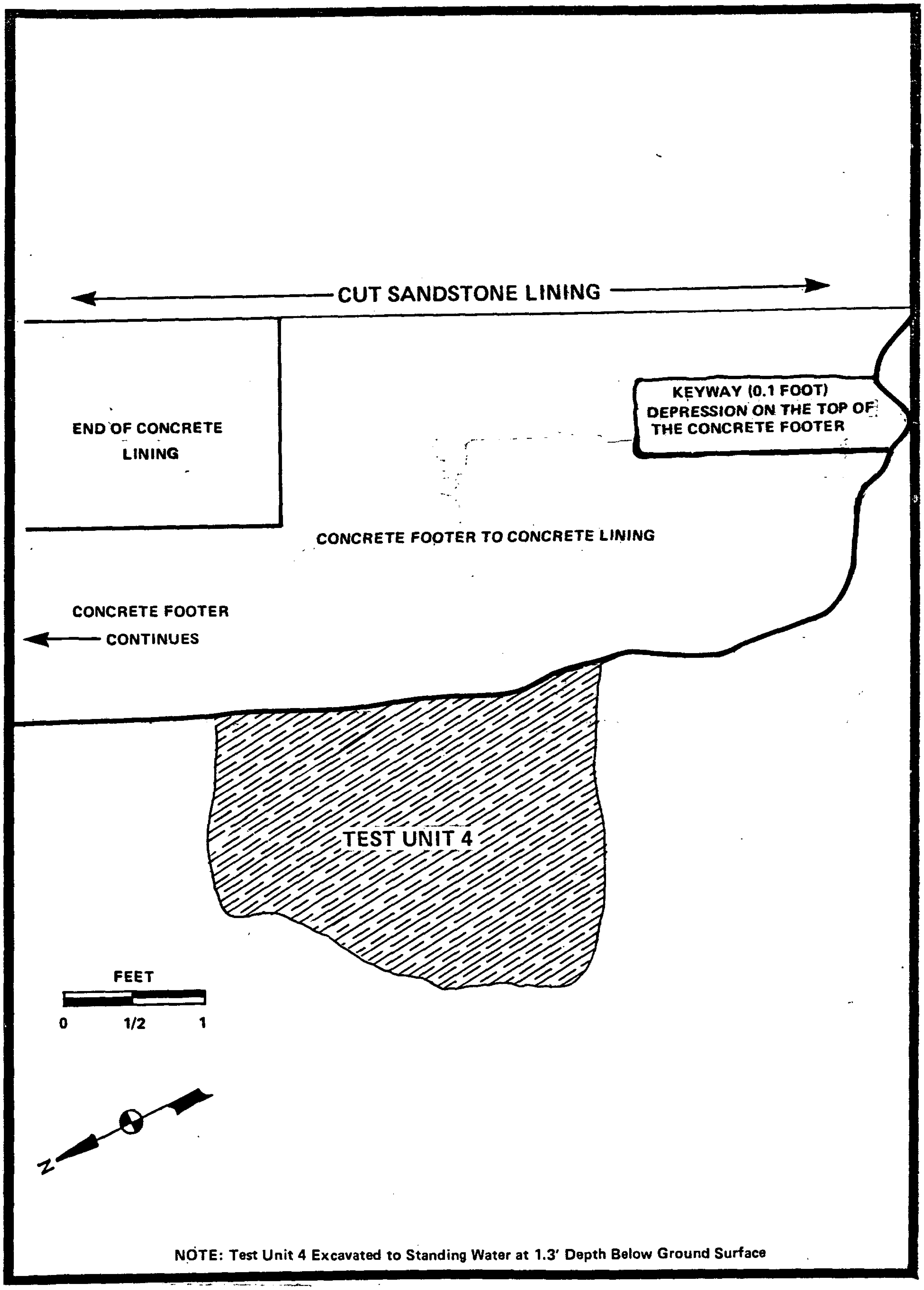
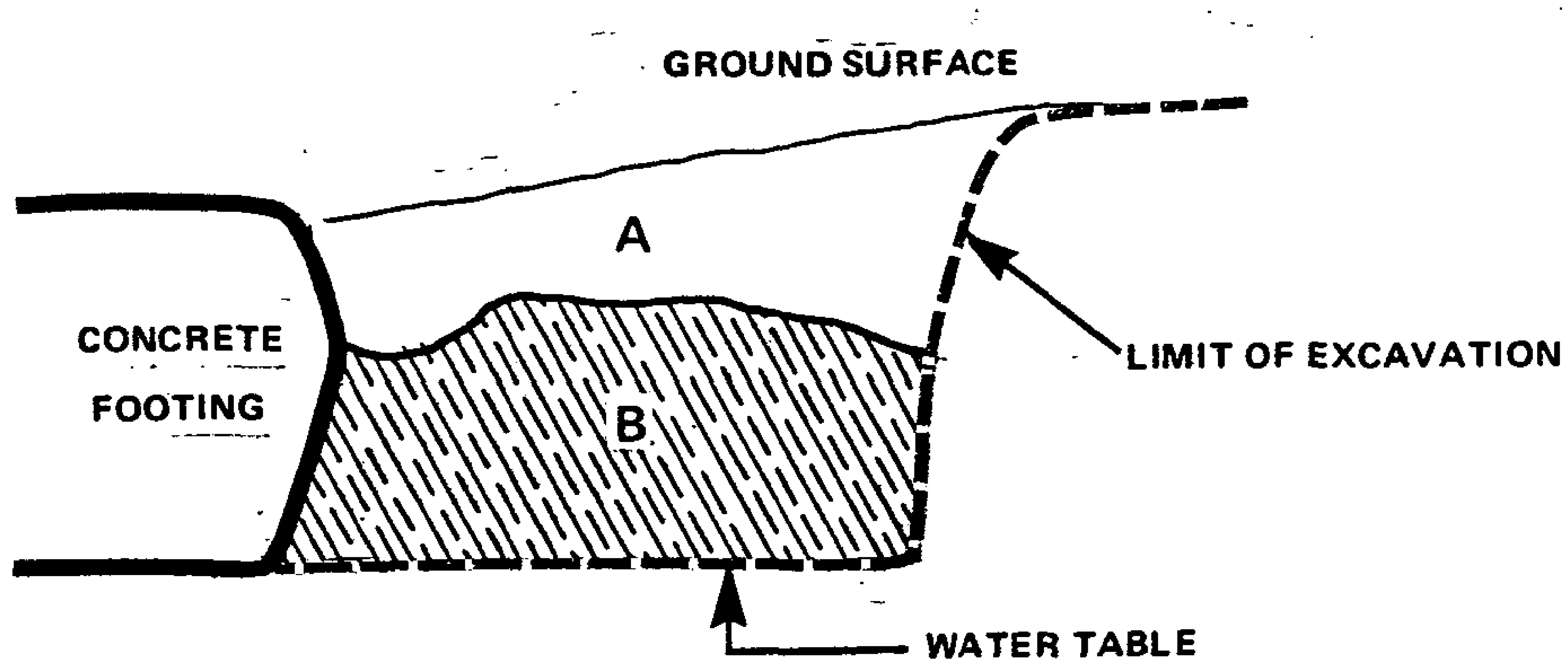


FIGURE 7 Test Unit 4, Plan View



LEGEND

A 10YR 4/1 DARK GRAY DECAYED SHALE

B 10YR 5/1 GRAY SILTY CLAY MOTTLED WITH A 10YR 7/6 YELLOW CLAY, VERY DENSE CLAY WITH SOME SHALE FRAGMENTS

FEET

0 1/2 1

NOTE: Concrete Footer Ends at the Same Depth as Water Table

FIGURE 8 Test Unit 4, South Profile

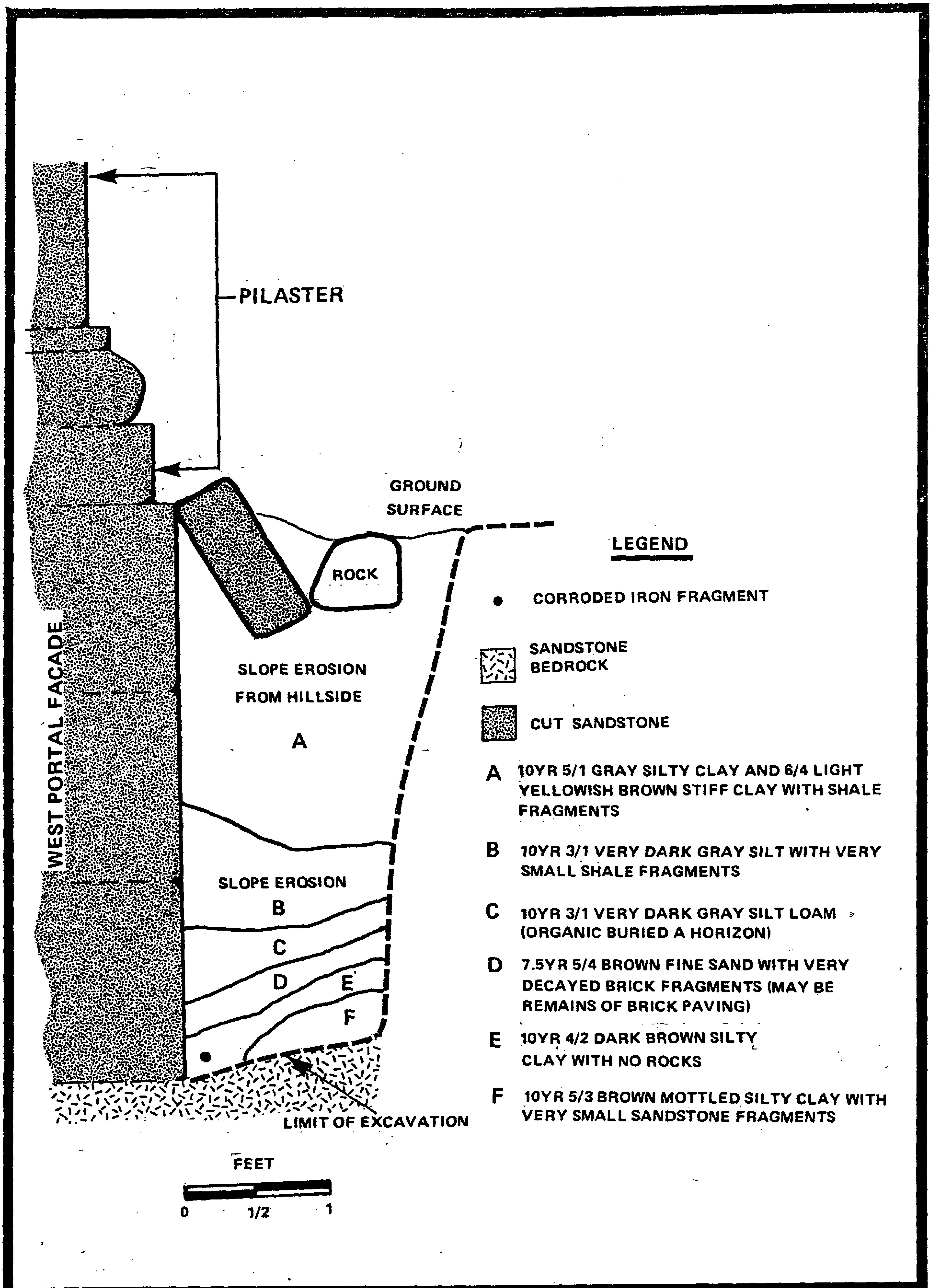
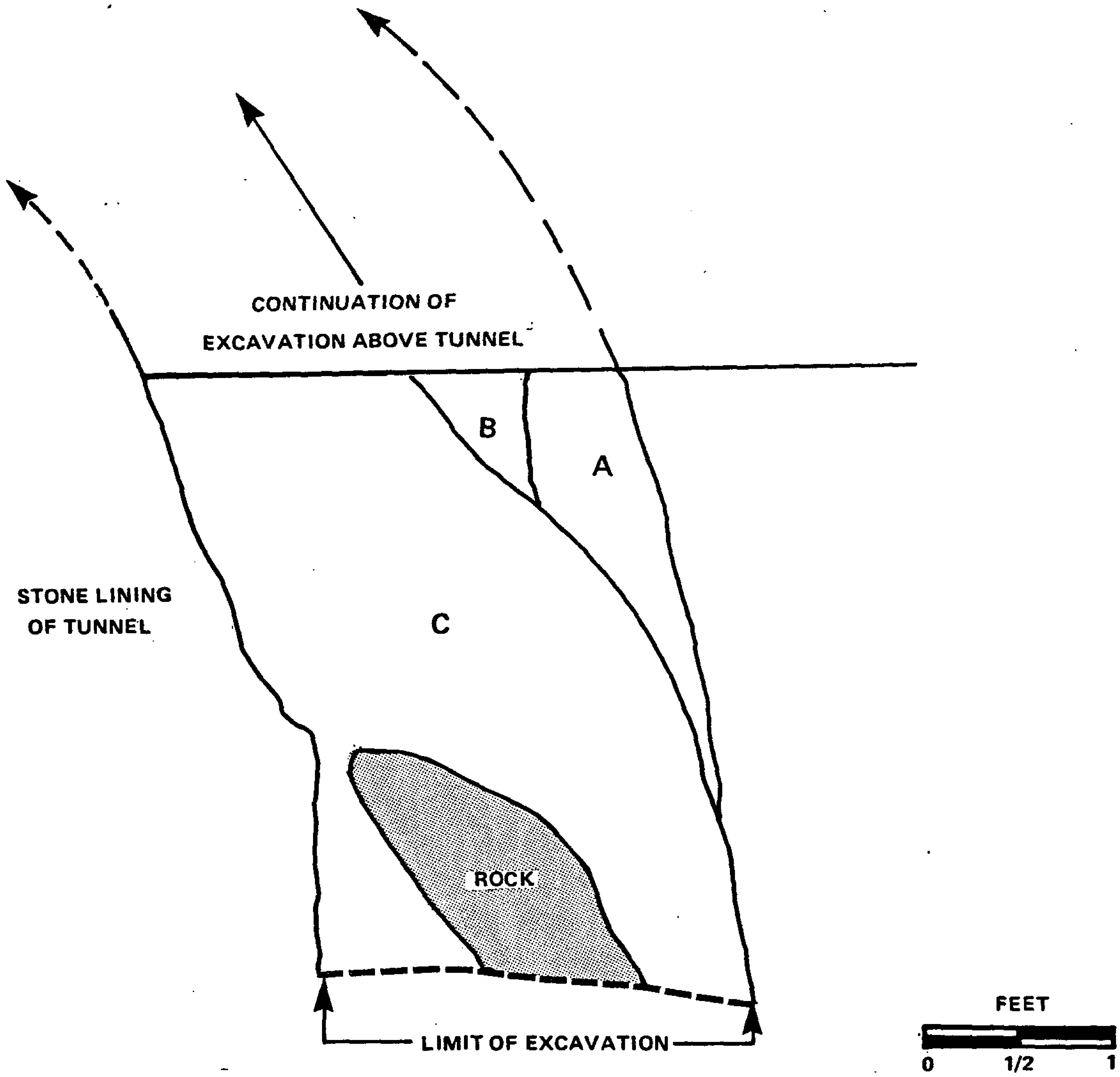


FIGURE 9 Test Unit 5, East Profile



LEGEND

A 10YR 3/2 VERY DARK GRAYISH BROWN SILT LOAM, HUMUS/ROOTS

B 7.5 YR 2/0 BLACK SILT

C 10YR 4/2 DARK GRAYISH BROWN SILTY CLAY WITH SANDSTONE FRAGMENTS

FIGURE 10 Test Unit 6, South Profile

silty loam with humus and roots. Stratum B was a 7.5YR 2/0 black silt, very light/loose in texture. This same stratum was also found in Test Units 2 and 3. Stratum C was a 10YR 4/2 dark grayish brown silty clay with sandstone fragments. This stratum was also found in Test Unit 4. No artifacts were observed in Test Unit 6.

III. INTERPRETATIONS AND RECOMMENDATIONS

The original bedrock floor of the tunnel was reached in three test units. The depths of the floor vary from 2 to 3.5 below present ground surface. The type of bedrock varied from siltstone to sandstone depending upon the location of the test unit. he historic grade of the Portage Railroad through the tunnel can be established from these tests.

The 48-inch concrete water pipe has greatly impacted the cultural resources within the tunnel. A large area of the tunnel floor was removed to facilitate the installation of the pipe. This has destroyed almost all evidence of the track. Only two track-related artifacts were recovered during archeological monitoring, a rail chair and a railroad spike. Neither artifacts was found in situ. No evidence track ballast, sleepers or other track-related features was seen. The installation of the concrete pipe also destroyed an earlier wooden water pipe installed by Bethlehem Steel.

There is no archeological evidence of the type of track used in the tunnel. An informant has stated that stone sleepers were removed from the tunnel in the 1950s by local residents (David Hessler, personal communication, August 22, 1990). These sleepers were probably pulled during the installation of the concrete water pipe and stored against the tunnel walls. It seems likely that the track in the tunnel was laid on stone sleepers rather than on wooden stringers.

Only small areas along the edges of the tunnel contain deposits undisturbed by the installation of the concrete water pipe. With the exception of Stratum F in Test Unit 3, these strata are the result of rockfall deposits.

The historic deposits found outside of the tunnel in Test Unit 5 are significant. Very little is known about the relationship between Engine House 1 and the tunnel. The brick and sand stratum found in this unit appears to be the remains of a brick paving. The area between the engine house and the tunnel was probably brick paved to form a solid working floor. The exact location of some of the engine house walls are not known. Tracing this brick and sand stratum west should lead to the east wall of the engine house.

It is recommended that, if possible, Staple Bend Tunnel should be re-opened and interpreted to the public. The tunnel, as part of the Allegheny Portage Railroad, was a great engineering feat. Interpretation of the tunnel's architecture, engineering and geology would be enhanced if visitors could walk into the tunnel. Any ground disturbing activities that will occur outside of the tunnel may have an impact on archeological resources that would require mitigation.

IV. REFERENCES CITED

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1990 Resident of Mineral Point, Pennsylvania. Personal communication, August 22, 1990.

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Toogood, Anna Coxe
1973 Historic Resource Study: Allegheny Portage Railroad National Historic Site, Pennsylvania. U.S. Department of Interior, National Park Service, Denver Service Center, Denver.

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JOB 90783
SHEET NO. 0 OF
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SCALE

CALCULATION INDEX

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JOB 90783 - 32
SHEET NO. 1 OF
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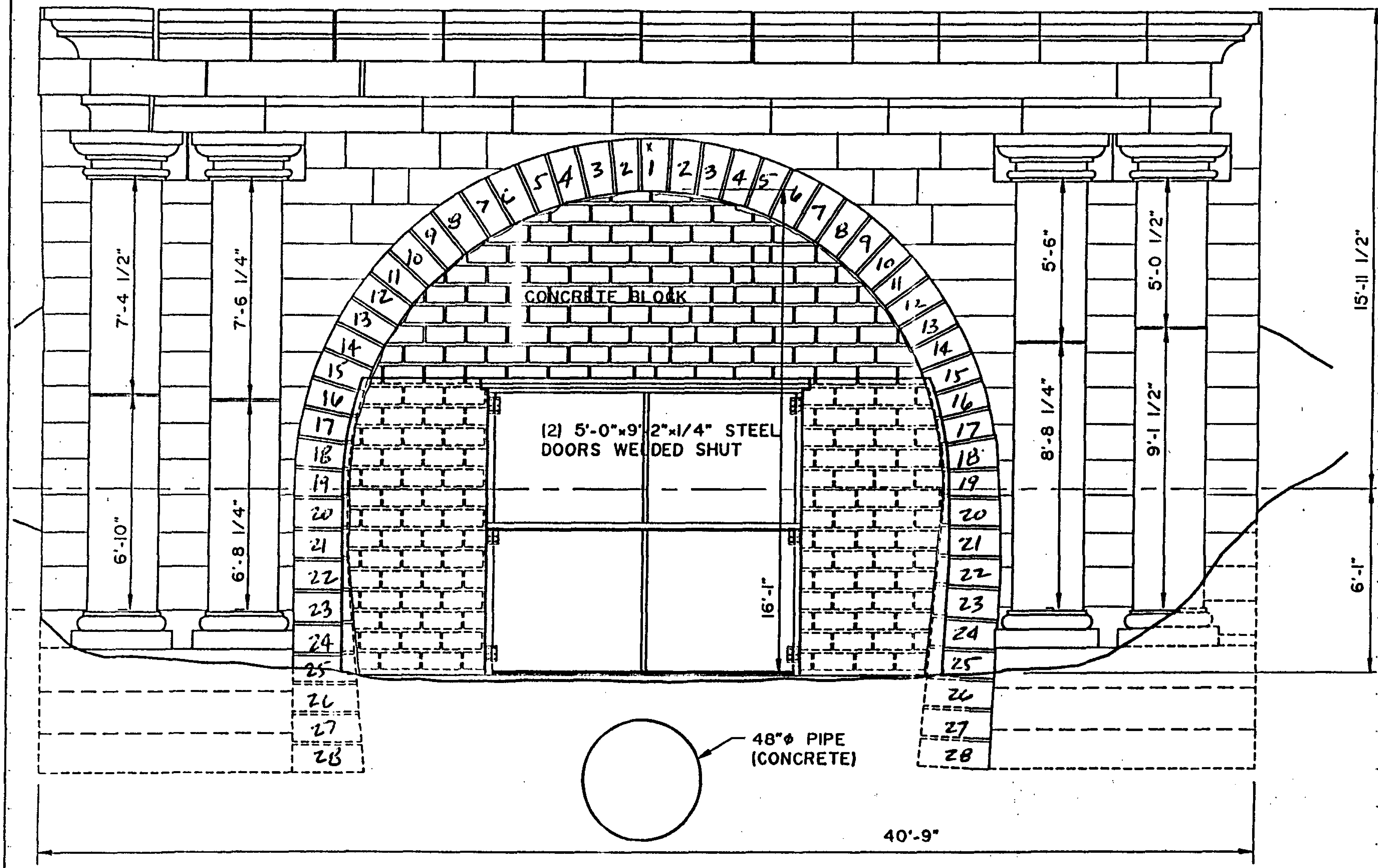
SCALE NOTES ON ARCH ANALYSIS

The following structural analysis of the dressed stone lining at each end of Staple Bend Tunnel was carried out to determine under what conditions the lining was structurally stable. The measured cross-section at the west portal was used as the basis of the analysis.

From the calculations, the arch appears to be stable under all uniform loading conditions to which it might be subjected--from no soil load to 20 feet of cover. The most critical stresses in the arch appear to occur in either stones 18, 19 or 20 which is at the point of tangency of the arch crown with the side wall. A very limited analysis was undertaken introducing effects of increased active soil load due to deformation of the arch. (Calculation sets 8 and 9.) It is concluded from these efforts that as the arch deforms, the soil loads will redistribute in a positive way so as to reduce the higher stress conditions at these critical "corner" stones.

An unbalanced load condition (calculation set 10) was also placed on the arch to envision what type of load unbalance may have existed to cause the rotation at the east portal. A five-foot difference was used. This condition would cause collapse. Thus, an unbalanced loading of only 2 or 3 feet of soil surcharge would cause considerable unbalanced stresses to occur in the arch.

The basic loading condition is noted in the upper right-hand corner of each three-page calculation set.



ELEVATION AT WESTERN END

SCALE: 1"=5'

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SHEET NO. 2 OF

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OUTSIDE RADIUS $= 10' + 22'' = 11.83'$
TYP. STONE DIM.

OUTSIDE STONE LENGTH $= \dfrac{2(142)\pi}{2(37)} = 12.06''$

37 STONES IN SEMICIRCLE

IF LENGTH OF RADIUS IS REDUCED 1''

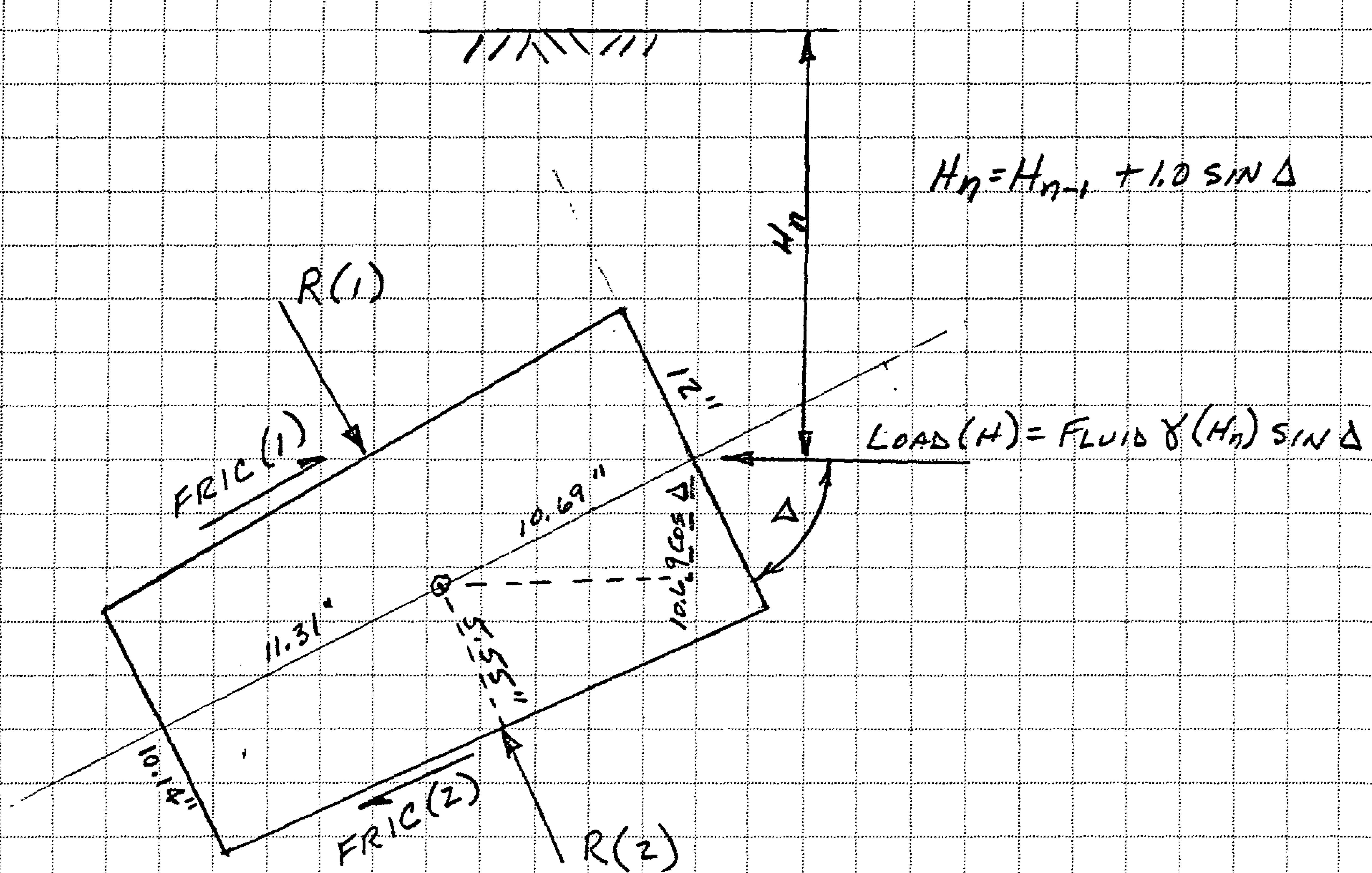
STONE LENGTH $= \dfrac{2(140)\pi}{2(37)} = 11.97''$ USE 12'' AS TYP. STONE.

INSIDE DIM. $= \dfrac{120}{142}(12) = 10.14'' \approx 10\frac{1}{8}''$

$$C.G. = \frac{10.14(22)(11) + 0.5(22)^2(1.86)(0.667)}{10.14(22) + 0.5(22)(1.86)} = 11.31''$$

$$5.07 + \frac{11.31}{22}(0.93) = 5.55''$$

STONE WEIGHT $= \left(\dfrac{12 + 10.14}{2}\right)(22)\left(\dfrac{1}{144}\right)(160\ PCF) = 270\ PLF$



HORIZONTAL LOAD DIAGRAM

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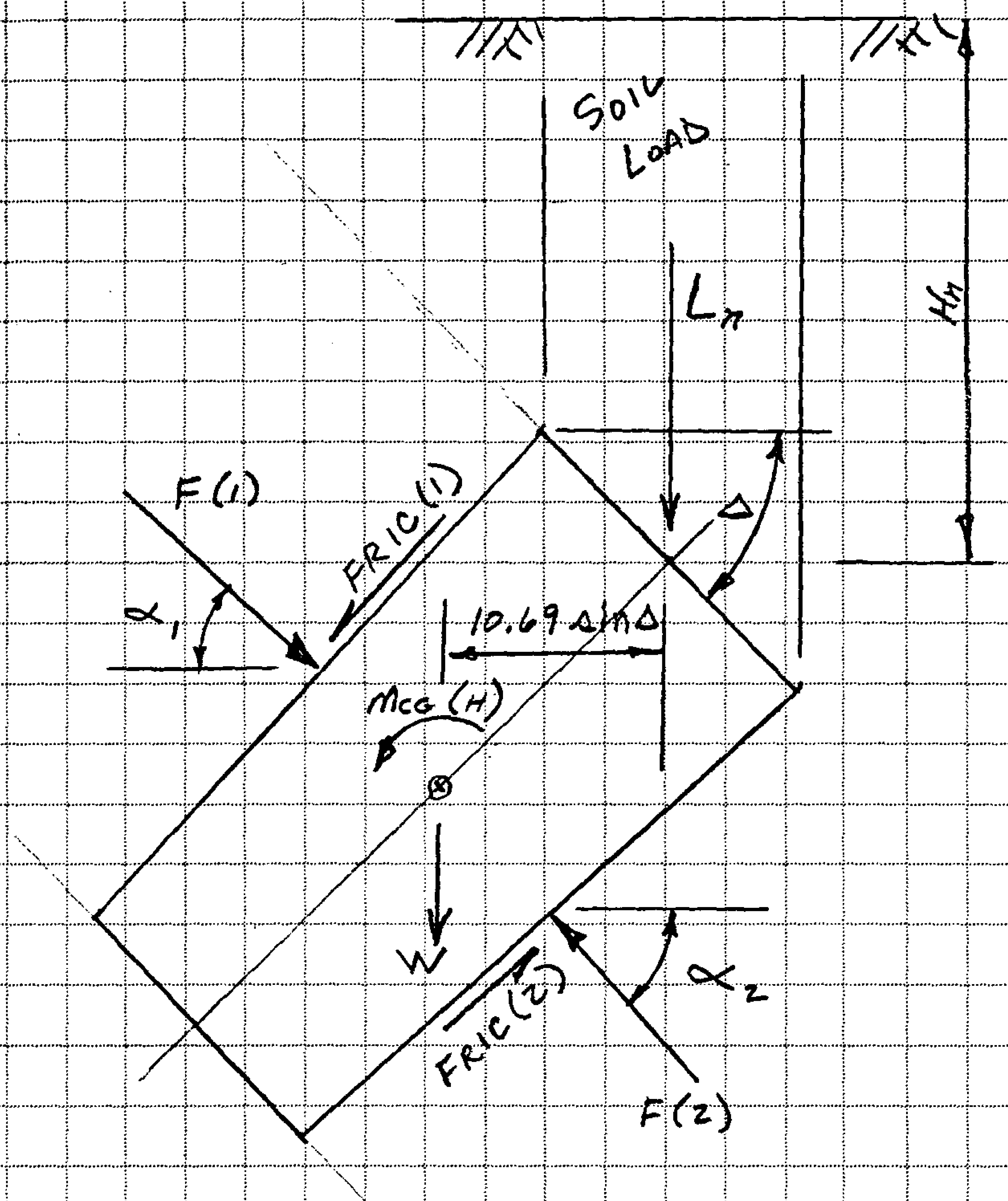
SCALE STAPLE BEND TUNNEL

$H_n = H_{n-1} + 1.0 \sin \Delta$

$L_n = \gamma (H_n)(1.0) \cos \Delta$



VERTICAL LOAD DIAGRAM

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SHEET NO. 5 OF
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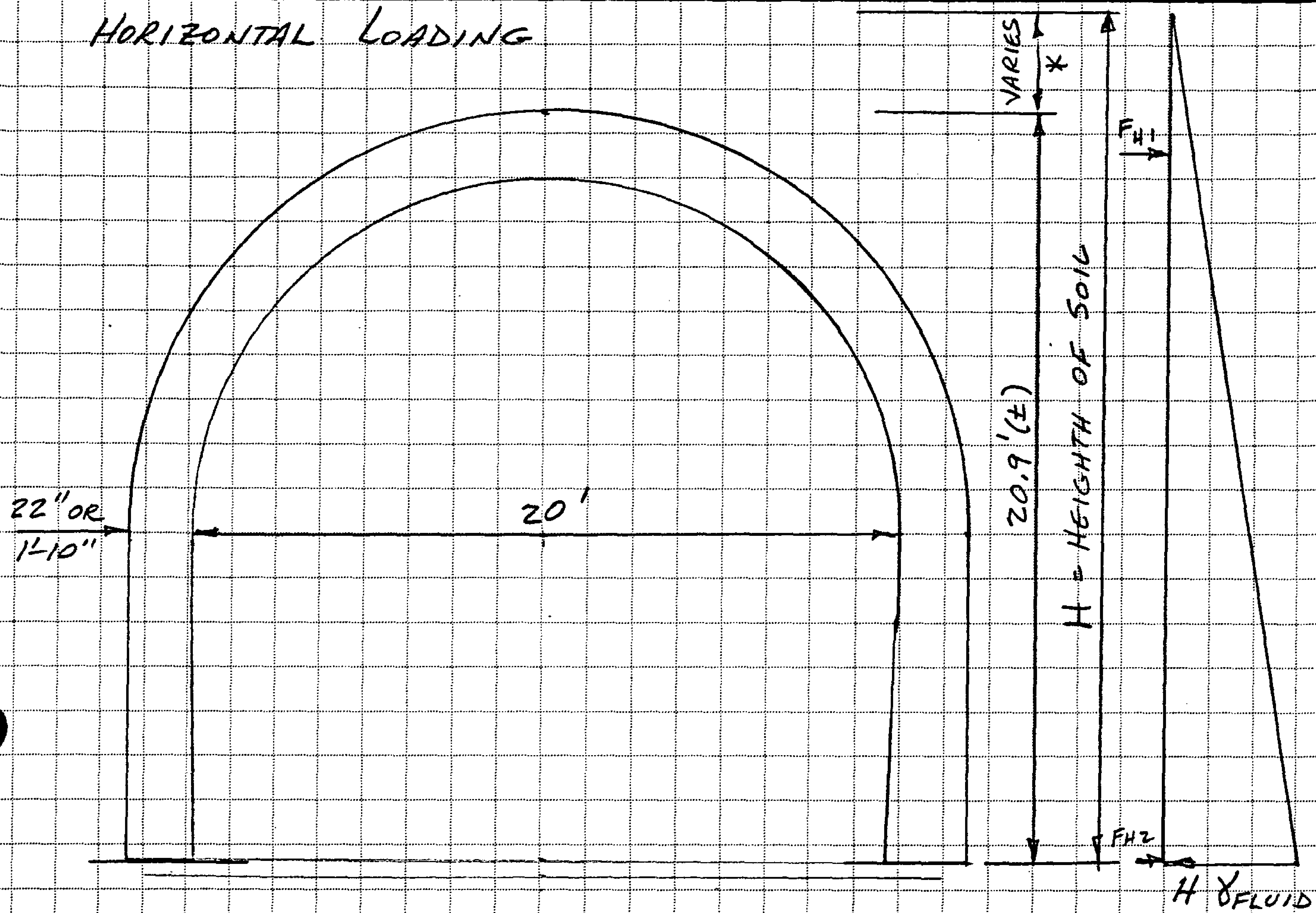
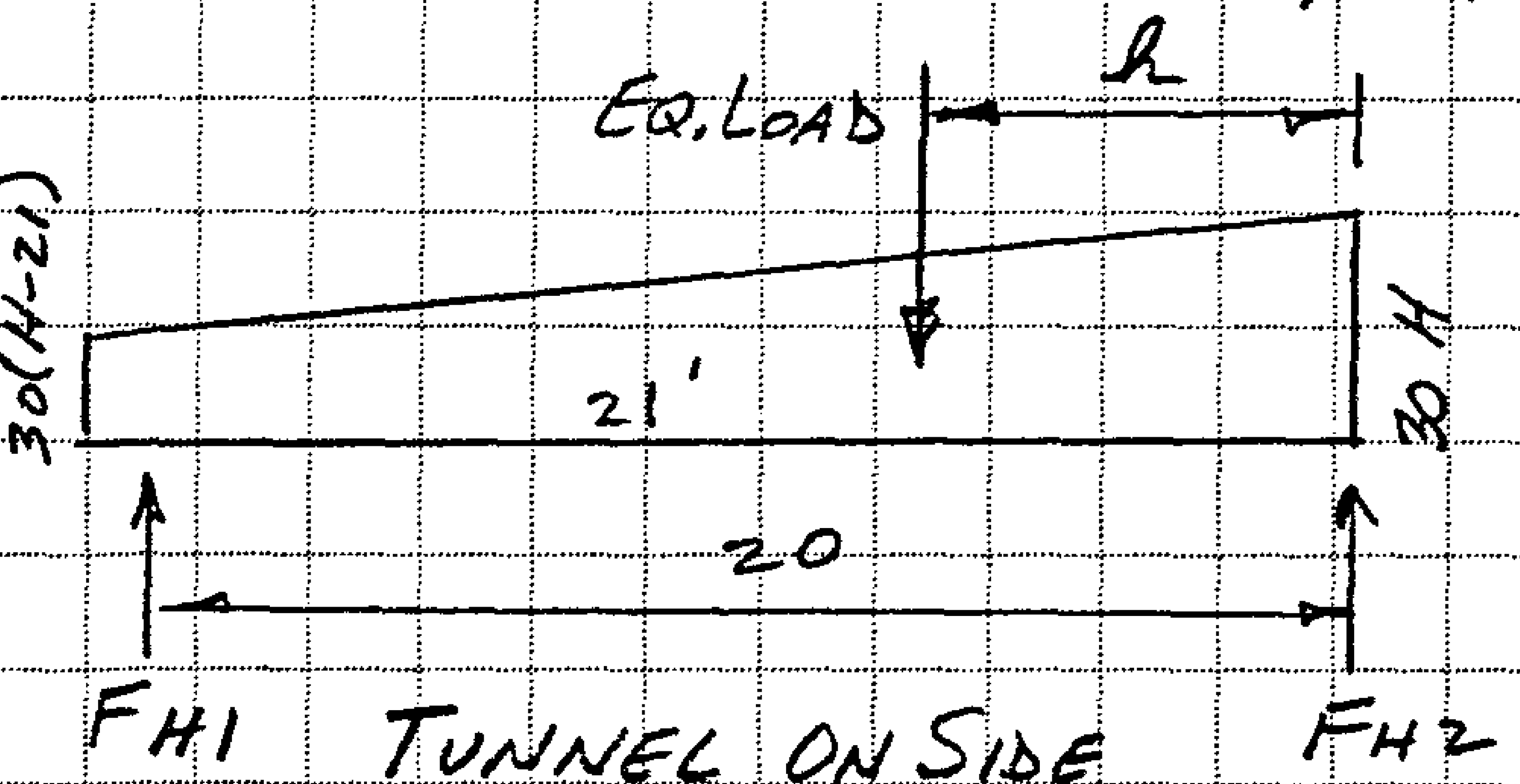
HORIZONTAL LOADING



* CALCULATED FOR 0', 3', 5', 10', 15', 20'



TUNNEL ON SIDE

$\gamma_{FLUID} = 30\ pcf$

$$h = \frac{\left[(21)^3(30) \div 6\right] + 30(H-21)(21)(10.5)}{(21)^2(30)(0.5) + 30(H-21)(21)}$$

$$h = \frac{46305 + 6615H - 138915}{6615 + 630H - 13230}$$

$$h = \frac{10.5H - 147}{H - 10.5}$$

$$EQ.LOAD = \frac{\left(30H + 30(H-21)\right)}{2}21$$

$$= 630H - 6615$$

$$F_{H1} = \frac{h}{20}(EQ.LOAD)$$

FILL HEIGTH	H	h	EQ LOAD	F_{H1}
0	21	7.0	6615	2315
3	24	7.8'	8505	3315
5	26	8.1'	9765	3955
10	31	8.7'	12915	5620
15	36	9.0'	16065	7230
20	41	9.3'	19215	8935

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SHEET NO. 6 OF
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CHECKED BY DATE
SCALE

TABLE 1 TABULATION SUMMARY OF STRESSES

Loading Cond.	Block	a(RZ) (in.)	Width of Stone W	RZ (in Kips)	Stress (psi) Left	Stress (psi) Right	FRIC(Z)	Shear Stress (psi)	Right Edge Dist.	Crit. Edge Dist.		
No Load	28	-6.37	29	7.425	0 psi	89 psi	.005	<1 psi	4.63"	4.63		
H=0	28	11.19	29	14.645	120	0	4.509	13	22.19	6.81	1.81	450
H=0	19	-4.71	22	12.215	0	108	.009	<1	6.29	6.29		
H=3	28	7.95	29	19.614	109	5	5.398	16	18.95	10.05	5.05	216
H=3	19	-6.53	22	17.184	0	214	.081	<1	4.47	4.47		
H=5	28	7.09	29	22.857	114	17	6.018	18	18.09	10.91	5.91	215
H=5	19	-6.97	22	20.427	0	282	0.155	<1	4.03	4.03		
H=10	28	5.53	29	31.133	127	52	7.502	22	16.53	12.47	7.47	
H=10	19	-7.56	22	28.703	0	464	.276	1	3.44	3.44		232
H=15	28	4.96	29	39.267	147	79	9.042	26	15.96	13.04	8.04	271
H=15	19	-7.77	22	36.837	0	634	.453	2	3.23	3.23		
H=20	28	4.25	29	47.647	158	116	10.486	30	15.25	13.75	8.75	≈320
H=20	19	-7.97	22	45.217	0	829	0.534	2	3.03	3.03		
H=20 PASSIVE 1	28	6.23	29	48.290	217	60	9.587	28	17.23	11.77		
	18	-7.51	22	45.666	0	727	2.313	9	3.49	3.49		
H=20	28	8.59	29	50.107	331	0	10.890	32	20.59	8.41		
PASSIVE 3	18	-7.43	22	47.502	0	750	2.709	11	3.52	3.52		

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JOB 90783-32
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SCALE HORIZONTAL LOAD ANALYSIS

COL.	HEADING	INPUT		
AO	R(1)	11 LATERAL LOAD	12 + BC 11	COPY
AQ	R(1V)	11 0	12 - BE 11	
AS	R(1H)	11 LATERAL LOAD	12 - BG 11	
AU	FRIC(1)	11 0	12 - BI 11	
AW	FRIC(1V)	11 0	12 - BK 11	
AY	FRIC(1H)	11 0	12 - BM 11	
BA	LOAD(H)	11 - 30 * O11 * @SIN(S11 * @PI/180)/1000		
BC	R(2)	11 - (+AQ11 * BU11 - AW11 * BU11 - AS11 * BW11 - AY11 * BW11 - BW11 * BA11)		
BE	R(2V)	11 + BC11 * @SIN(AK11 * @PI/180)		
BG	R(2H)	11 - BC11 * @COS(AK11 * @PI/180)		
BI	FRIC(2)	11 (-AS11 - AY11 - BA11 - BG11) /BU11		
BK	FRIC(2V)	11 + BI 11 * @COS(AK11 * @PI/180)		
BM	FRIC(2H)	11 + BI 11 * @SIN(AK11 * @PI/180)		
BO	M(CGH)	11 0	12 + BO11 AU12 * 5.55 + BI12 * 5.55 + BA12 * 10.69 * @COS(S12 * @PI/180)	
BQ	SIN α1	11 @SIN(AI 11)		
BS	COS α1	11 @COS(AI 11)		
BU	SIN α2	11 @SIN(AK11)		
BW	COS α2	11 @COS(AK 11)		
BO		29 CHANGE 5.55 TO 6.0		COPY

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SHEET NO. 8 OF
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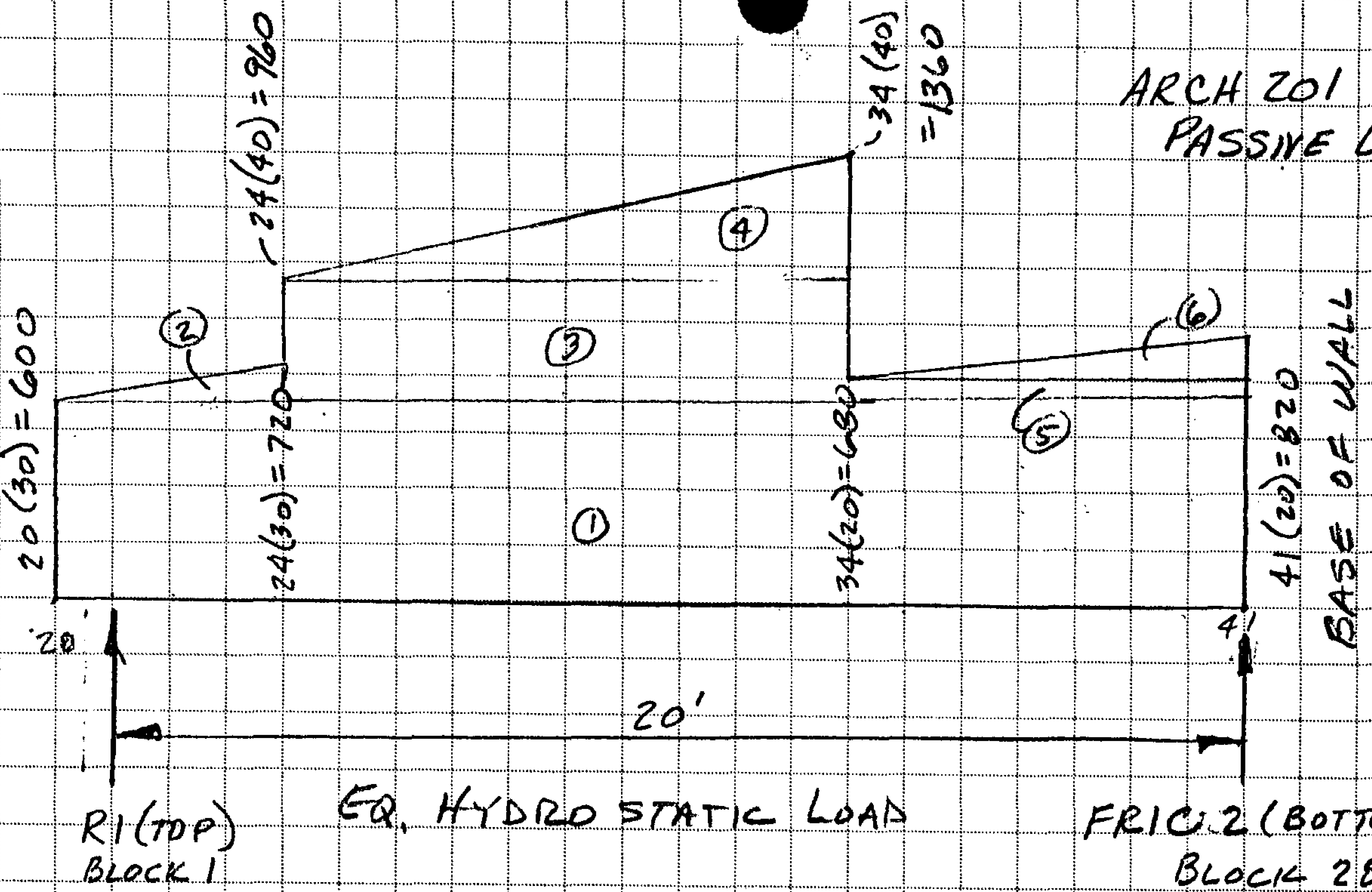
SCALE VERTICAL LOAD ANALYSIS

COL.	HEADING	IMPUT
C	F(1)	11 -G11 12 -U11 COPY
E	F(1V)	11 0 12 -W11 COPY
G	F(1H)	11 -(-0.135+Q11)/BU11 12 -Y11 COPY
I	FRIC(1)	11 0 12 -AA11
K	FRIC(1V)	11 0 12 -AC11
M	FRIC(1H)	11 0 12 -AE11
O	H	11 COVER +(1*@SIN(S11*3.1416/180))
		12 +O11 + (1*@SIN(S12*3.1416/180))
Q	LOAD(V)	11 -(120 * O11 * @COS (S11 *@PI/180)/1000/2
		12 SAME AS 11 W/NO /2 AT END
S	DELTA	11 +AK11-2.5
U	F(2)	11 +W11/BU11
W	F(2V)	11 -E11+0.135-Q11 12 -E12+0.270-Q12
Y	F(2H)	11 -U11*@COS(AK11*@PI/180)
AA	FRIC(2)	11 (+G11+M11+Y11)/BU11
AC	FRIC(2V)	11 +AA11*BW11
AE	FRIC(2H)	11 +AA11 * BU11
AG	M(G V)	11 0 12 -AA12*5.55+I12*5.55-Q12*@SIN
		(S12*@PI/180) + AG11 COPY
		29 CHANGE 5.55 TO 6.0
AI	α1	11 0 12 +AK12-5 COPY
AK	α2	11 2.5 12 5+AK11 COPY

NOTE:
COLUMN O IMPUT "COVER" IN FEET AS HEIGHTH OF FILL ABOVE LINING.
STONE 1 F(1) & FRIC (1) LOADS ARE AT CENTER OF STONE.

ARCH 201
PASSIVE LOADING 1



	R1 (TOP)	FRIC. 2 (BOTTOM)
1 $600(21)\frac{10.5}{20}$ =	6615	5985
2 $120(4)(\frac{1}{2})(\frac{18.3}{20})$ =	220	20
3 $360(10)(\frac{12}{20})$ =	2160	1440
4 $400(10)(\frac{1}{2})(\frac{10.3}{20})$ =	1030	970
5 $80(7)(\frac{3.5}{20})$ =	98	462
6 $140(7)(\frac{1}{2})(\frac{2.3}{20})$ =	56	434
	10179	9311

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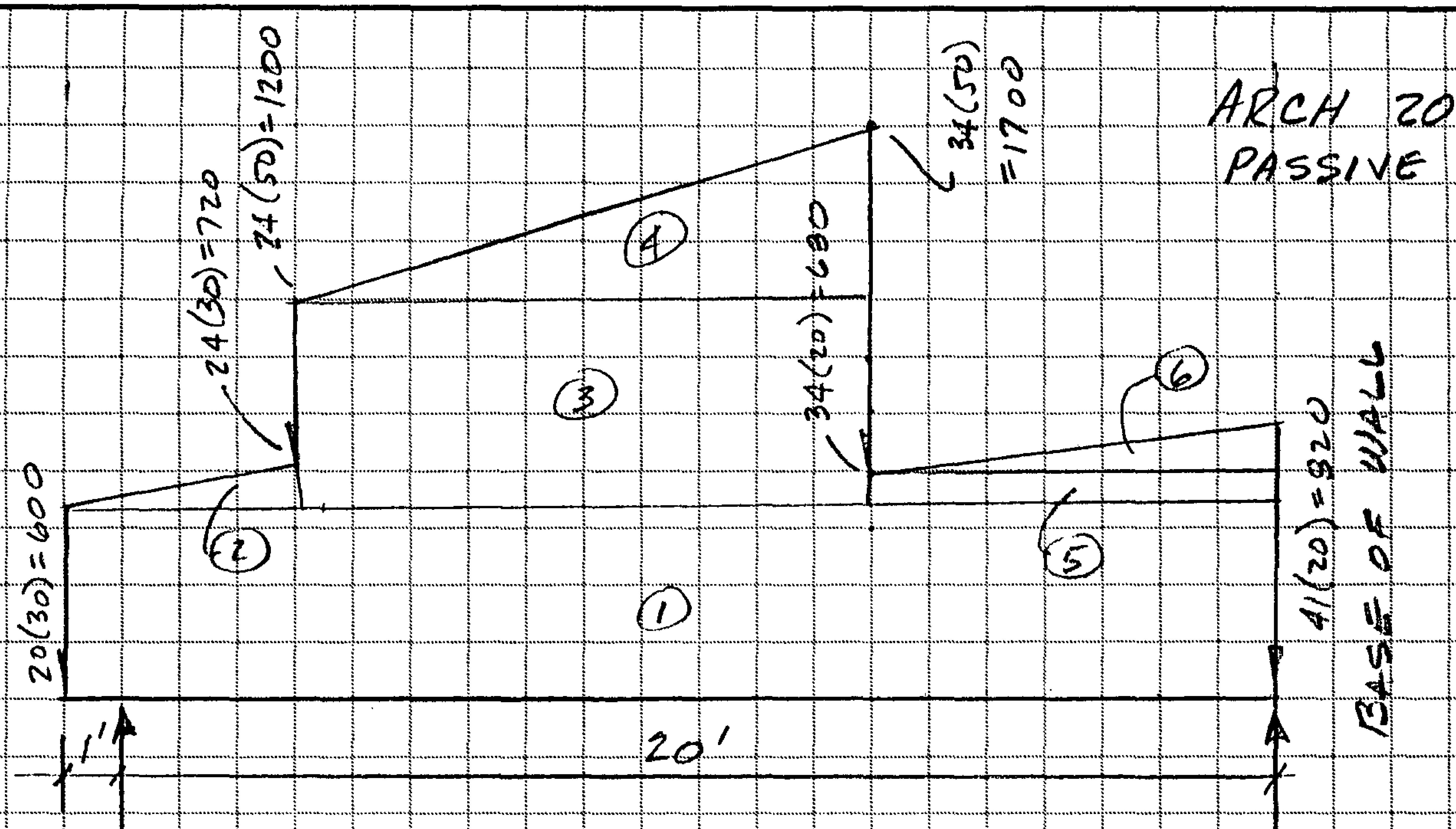
ARCH 203
PASSIVE LOADING 3



EQ, HYDROSTATIC LOAD

		R(1) (TOP)	FRIC 2 (BOT)
1		6615	5985
2		220	20
3	$600(10)(\frac{12}{20})$	3600	2400
4	$500(10)(\frac{1}{2})(\frac{10.3}{20})$	1288	1212
5		98	462
6		56	434
		11,877	10,513.

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STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCHO-DISC1
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=0 (NO SOIL LOAD)
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

NO SOIL, ARCH ONLY

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-3.095	0.000	3.095	0.000	0.000	0.000	0.000	0.000	0.000	3.095	0.135	-3.092	0.068	0.067	0.003	0.000	0.000	2.500
BLOCK 2	-3.095	-0.135	3.092	-0.068	-0.067	-0.003	0.087	0.000	5.000	3.103	0.405	-3.076	0.098	0.097	0.013	-0.918	2.500	7.500
BLOCK 3	-3.103	-0.405	3.076	-0.098	-0.097	-0.013	0.261	0.000	10.000	3.119	0.675	-3.045	0.087	0.085	0.019	-1.943	7.500	12.500
BLOCK 4	-3.119	-0.675	3.045	-0.087	-0.085	-0.019	0.520	0.000	15.000	3.143	0.945	-2.997	0.096	0.091	0.029	-2.956	12.500	17.500
BLOCK 5	-3.143	-0.945	2.997	-0.096	-0.091	-0.029	0.862	0.000	20.000	3.175	1.215	-2.933	0.092	0.085	0.035	-3.996	17.500	22.500
BLOCK 6	-3.175	-1.215	2.933	-0.092	-0.085	-0.035	1.284	0.000	25.000	3.216	1.485	-2.853	0.099	0.087	0.046	-5.052	22.500	27.500
BLOCK 7	-3.216	-1.485	2.853	-0.099	-0.087	-0.046	1.784	0.000	30.000	3.266	1.755	-2.755	0.097	0.082	0.052	-6.140	27.500	32.500
BLOCK 8	-3.266	-1.755	2.755	-0.097	-0.082	-0.052	2.358	0.000	35.000	3.326	2.025	-2.639	0.104	0.083	0.063	-7.259	32.500	37.500
BLOCK 9	-3.326	-2.025	2.639	-0.104	-0.083	-0.063	3.001	0.000	40.000	3.397	2.295	-2.505	0.105	0.078	0.071	-8.421	37.500	42.500
BLOCK 10	-3.397	-2.295	2.505	-0.105	-0.078	-0.071	3.708	0.000	45.000	3.479	2.565	-2.350	0.113	0.076	0.083	-9.630	42.500	47.500
BLOCK 11	-3.479	-2.565	2.350	-0.113	-0.076	-0.083	4.474	0.000	50.000	3.573	2.835	-2.175	0.116	0.071	0.092	-10.899	47.500	52.500
BLOCK 12	-3.573	-2.835	2.175	-0.116	-0.071	-0.092	5.293	0.000	55.000	3.682	3.105	-1.978	0.125	0.067	0.105	-12.235	52.500	57.500
BLOCK 13	-3.682	-3.105	1.978	-0.125	-0.067	-0.105	6.159	0.000	60.000	3.805	3.375	-1.757	0.131	0.060	0.116	-13.653	57.500	62.500
BLOCK 14	-3.805	-3.375	1.757	-0.131	-0.060	-0.116	7.065	0.000	65.000	3.945	3.645	-1.510	0.142	0.054	0.131	-15.167	62.500	67.500
BLOCK 15	-3.945	-3.645	1.510	-0.142	-0.054	-0.131	8.005	0.000	70.000	4.105	3.915	-1.234	0.151	0.045	0.144	-16.794	67.500	72.500
BLOCK 16	-4.105	-3.915	1.234	-0.151	-0.045	-0.144	8.971	0.000	75.000	4.287	4.185	-0.928	0.166	0.036	0.162	-18.556	72.500	77.500
BLOCK 17	-4.287	-4.185	0.928	-0.166	-0.036	-0.162	9.956	0.000	80.000	4.493	4.455	-0.587	0.180	0.024	0.179	-20.481	77.500	82.500
BLOCK 18	-4.493	-4.455	0.587	-0.180	-0.024	-0.179	10.952	0.000	85.000	4.730	4.725	-0.206	0.202	0.009	0.201	-22.601	82.500	87.500
BLOCK 19	-4.730	-4.725	0.206	-0.202	-0.009	-0.201	11.952	0.000	90.000	4.995	4.995	0.000	0.005	0.000	0.005	-23.840	87.500	90.000
BLOCK 20	-4.995	-4.995	0.000	-0.005	0.000	-0.005	12.952	0.000	90.000	5.265	5.265	0.000	-0.005	0.000	-0.005	-23.840	90.000	90.000
BLOCK 21	-5.265	-5.265	0.000	0.005	0.000	0.005	13.952	0.000	90.000	5.535	5.535	0.000	0.005	0.000	0.005	-23.840	90.000	90.000
BLOCK 22	-5.535	-5.535	0.000	-0.005	0.000	-0.005	14.952	0.000	90.000	5.805	5.805	0.000	-0.005	0.000	-0.005	-23.840	90.000	90.000
BLOCK 23	-5.805	-5.805	0.000	0.005	0.000	0.005	15.952	0.000	90.000	6.075	6.075	0.000	0.005	0.000	0.005	-23.840	90.000	90.000
BLOCK 24	-6.075	-6.075	0.000	-0.005	0.000	-0.005	16.952	0.000	90.000	6.345	6.345	0.000	-0.005	0.000	-0.005	-23.840	90.000	90.000
BLOCK 25	-6.345	-6.345	0.000	0.005	0.000	0.005	17.952	0.000	90.000	6.615	6.615	0.000	0.005	0.000	0.005	-23.840	90.000	90.000
BLOCK 26	-6.615	-6.615	0.000	-0.005	0.000	-0.005	18.952	0.000	90.000	6.885	6.885	0.000	-0.005	0.000	-0.005	-23.840	90.000	90.000
BLOCK 27	-6.885	-6.885	0.000	0.005	0.000	0.005	19.952	0.000	90.000	7.155	7.155	0.000	0.005	0.000	0.005	-23.840	90.000	90.000
BLOCK 28	-7.155	-7.155	0.000	-0.005	0.000	-0.005	20.952	0.000	90.000	7.425	7.425	0.000	-0.005	0.000	-0.005	-23.840	90.000	90.000

0.000 Weight of Soil Load
7.425 Combined Weight of Soil and Arch

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

AM AN	AO AP	AQ AR	AS AT	AU AV	AW AX	AY AZ	BA BB	BC BD	BE BF	BG BH	BI BJ	BK BL	BM BN	BO BP	BQ BR	BS BT	BU BV	BW BX
	R(1)	R(1V)	R(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	Load(H)	R(2)	R(2V)	R(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgH)	SIN ALPHA 1	COS ALPHA 1	SIN ALPHA 2	COS ALPHA 2
BLOCK 1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.044	0.999
BLOCK 2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.044	0.999	0.131	0.991
BLOCK 3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.131	0.991	0.216	0.976
BLOCK 4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.216	0.976	0.301	0.954
BLOCK 5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.301	0.954	0.383	0.924
BLOCK 6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.383	0.924	0.462	0.887
BLOCK 7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.462	0.887	0.537	0.843
BLOCK 8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.537	0.843	0.609	0.793
BLOCK 9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.609	0.793	0.676	0.737
BLOCK 10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.676	0.737	0.737	0.676
BLOCK 11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.737	0.676	0.793	0.609
BLOCK 12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.793	0.609	0.843	0.537
BLOCK 13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.843	0.537	0.887	0.462
BLOCK 14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.887	0.462	0.924	0.383
BLOCK 15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.924	0.383	0.954	0.301
BLOCK 16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.954	0.301	0.976	0.216
BLOCK 17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.976	0.216	0.991	0.131
BLOCK 18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.991	0.131	0.999	0.044
BLOCK 19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.999	0.044	1.000	0.000
BLOCK 20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000
BLOCK 28	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	1.000	0.000

0.000 Total lateral load from soil (typ.)

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-3.095	0.000	0.000	0.000	3.095	0.000	0.068			0.000	0.000	
BLOCK 2	-3.095	0.000	-0.068	-0.918	3.103	-0.296	0.098			-0.918	-0.296	
BLOCK 3	-3.103	-0.296	-0.098	-1.943	3.119	-0.625	0.087			-1.025	-0.329	
BLOCK 4	-3.119	-0.625	-0.087	-2.956	3.143	-0.947	0.096			-1.013	-0.322	
BLOCK 5	-3.143	-0.947	-0.096	-3.996	3.175	-1.275	0.092			-1.040	-0.328	
BLOCK 6	-3.175	-1.275	-0.092	-5.052	3.216	-1.603	0.099			-1.056	-0.328	
BLOCK 7	-3.216	-1.603	-0.099	-6.140	3.266	-1.936	0.097			-1.088	-0.333	
BLOCK 8	-3.266	-1.936	-0.097	-7.259	3.326	-2.272	0.104			-1.119	-0.336	
BLOCK 9	-3.326	-2.272	-0.104	-8.421	3.397	-2.614	0.105			-1.162	-0.342	
BLOCK 10	-3.397	-2.614	-0.105	-9.630	3.479	-2.962	0.113			-1.209	-0.348	
BLOCK 11	-3.479	-2.962	-0.113	-10.899	3.573	-3.317	0.116			-1.269	-0.355	
BLOCK 12	-3.573	-3.317	-0.116	-12.235	3.682	-3.680	0.125			-1.336	-0.363	
BLOCK 13	-3.682	-3.680	-0.125	-13.653	3.805	-4.053	0.131			-1.418	-0.373	
BLOCK 14	-3.805	-4.053	-0.131	-15.167	3.945	-4.436	0.142			-1.513	-0.384	
BLOCK 15	-3.945	-4.436	-0.142	-16.794	4.105	-4.833	0.151			-1.627	-0.396	
BLOCK 16	-4.105	-4.833	-0.151	-18.556	4.287	-5.244	0.166			-1.762	-0.411	
BLOCK 17	-4.287	-5.244	-0.166	-20.481	4.493	-5.672	0.180			-1.925	-0.428	
BLOCK 18	-4.493	-5.672	-0.180	-22.601	4.730	-6.120	0.202			-2.120	-0.448	
BLOCK 19	-4.730	-6.120	-0.202	-23.840	4.995	-6.368	0.005			-1.239	-0.248	
BLOCK 20	-4.995	-6.368	-0.005	-23.840	5.265	-6.368	-0.005	-0.001	-0.053	0.000	0.000	-0.011
BLOCK 21	-5.265	-6.368	0.005	-23.840	5.535	-6.368	0.005	0.001	0.051	0.000	0.000	-0.001
BLOCK 22	-5.535	-6.368	-0.005	-23.840	5.805	-6.368	-0.005	-0.001	-0.048	0.000	0.000	-0.011
BLOCK 23	-5.805	-6.368	0.005	-23.840	6.075	-6.368	0.005	0.001	0.046	0.000	0.000	-0.001
BLOCK 24	-6.075	-6.368	-0.005	-23.840	6.345	-6.368	-0.005	-0.001	-0.044	0.000	0.000	-0.010
BLOCK 25	-6.345	-6.368	0.005	-23.840	6.615	-6.368	0.005	0.001	0.042	0.000	0.000	-0.001
BLOCK 26	-6.615	-6.368	-0.005	-23.840	6.885	-6.368	-0.005	-0.001	-0.041	0.000	0.000	-0.010
BLOCK 27	-6.885	-6.368	0.005	-23.840	7.155	-6.368	0.005	0.001	0.039	0.000	0.000	-0.002
BLOCK 28	-7.155	-6.368	-0.005	-23.840	7.425	-6.368	-0.005	-0.001	-0.038	0.000	0.000	-0.010

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH1-DISC2
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=0
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL, LEVEL WITH TOP OF ARCH

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-3.095	0.000	3.095	0.000	0.000	0.000	0.000	0.000	0.000	3.095	0.135	-3.092	0.068	0.067	0.003	0.000	0.000	2.500
BLOCK 2	-3.095	-0.135	3.092	-0.068	-0.067	-0.003	0.087	-0.010	5.000	3.183	0.415	-3.155	-0.508	-0.504	-0.066	2.448	2.500	7.500
BLOCK 3	-3.183	-0.415	3.155	0.508	0.504	0.066	0.261	-0.031	10.000	3.309	0.716	-3.231	-0.041	-0.040	-0.009	5.505	7.500	12.500
BLOCK 4	-3.309	-0.716	3.231	0.041	0.040	0.009	0.520	-0.060	15.000	3.480	1.046	-3.319	-0.264	-0.251	-0.079	7.213	12.500	17.500
BLOCK 5	-3.480	-1.046	3.319	0.264	0.251	0.079	0.862	-0.097	20.000	3.694	1.414	-3.413	-0.038	-0.035	-0.015	8.920	17.500	22.500
BLOCK 6	-3.694	-1.414	3.413	0.038	0.035	0.015	1.284	-0.140	25.000	3.949	1.823	-3.503	-0.163	-0.144	-0.075	10.094	22.500	27.500
BLOCK 7	-3.949	-1.823	3.503	0.163	0.144	0.075	1.784	-0.185	30.000	4.241	2.279	-3.577	0.001	0.001	0.001	11.082	27.500	32.500
BLOCK 8	-4.241	-2.279	3.577	-0.001	-0.001	-0.001	2.358	-0.232	35.000	4.567	2.781	-3.624	-0.078	-0.062	-0.048	11.640	32.500	37.500
BLOCK 9	-4.567	-2.781	3.624	0.078	0.062	0.048	3.001	-0.276	40.000	4.924	3.326	-3.630	0.061	0.045	0.041	11.913	37.500	42.500
BLOCK 10	-4.924	-3.326	3.630	-0.061	-0.045	-0.041	3.708	-0.315	45.000	5.305	3.911	-3.584	0.007	0.005	0.005	11.758	42.500	47.500
BLOCK 11	-5.305	-3.911	3.584	-0.007	-0.005	-0.005	4.474	-0.345	50.000	5.705	4.526	-3.473	0.133	0.081	0.106	11.245	47.500	52.500
BLOCK 12	-5.705	-4.526	3.473	-0.133	-0.081	-0.106	5.293	-0.364	55.000	6.119	5.160	-3.287	0.095	0.051	0.080	10.279	52.500	57.500
BLOCK 13	-6.119	-5.160	3.287	-0.095	-0.051	-0.080	6.159	-0.370	60.000	6.539	5.800	-3.019	0.212	0.098	0.188	8.895	57.500	62.500
BLOCK 14	-6.539	-5.800	3.019	-0.212	-0.098	-0.188	7.065	-0.358	65.000	6.958	6.428	-2.663	0.182	0.070	0.168	7.030	62.500	67.500
BLOCK 15	-6.958	-6.428	2.663	-0.182	-0.070	-0.168	8.005	-0.329	70.000	7.368	7.027	-2.216	0.292	0.088	0.279	4.706	67.500	72.500
BLOCK 16	-7.368	-7.027	2.216	-0.292	-0.088	-0.279	8.971	-0.279	75.000	7.759	7.575	-1.679	0.263	0.057	0.257	1.890	72.500	77.500
BLOCK 17	-7.759	-7.575	1.679	-0.263	-0.057	-0.257	9.956	-0.207	80.000	8.122	8.053	-1.060	0.365	0.048	0.362	-1.395	77.500	82.500
BLOCK 18	-8.122	-8.053	1.060	-0.365	-0.048	-0.362	10.952	-0.115	85.000	8.445	8.437	-0.368	0.330	0.014	0.330	-5.139	82.500	87.500
BLOCK 19	-8.445	-8.437	0.368	-0.330	-0.014	-0.330	11.952	0.000	90.000	8.707	8.707	0.000	0.039	0.000	0.039	-7.351	87.500	90.000
BLOCK 20	-8.707	-8.707	0.000	-0.039	0.000	-0.039	12.952	0.000	90.000	8.977	8.977	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 21	-8.977	-8.977	0.000	0.039	0.000	0.039	13.952	0.000	90.000	9.247	9.247	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 22	-9.247	-9.247	0.000	-0.039	0.000	-0.039	14.952	0.000	90.000	9.517	9.517	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 23	-9.517	-9.517	0.000	0.039	0.000	0.039	15.952	0.000	90.000	9.787	9.787	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 24	-9.787	-9.787	0.000	-0.039	0.000	-0.039	16.952	0.000	90.000	10.057	10.057	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 25	-10.057	-10.057	0.000	0.039	0.000	0.039	17.952	0.000	90.000	10.327	10.327	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 26	-10.327	-10.327	0.000	-0.039	0.000	-0.039	18.952	0.000	90.000	10.597	10.597	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 27	-10.597	-10.597	0.000	0.039	0.000	0.039	19.952	0.000	90.000	10.867	10.867	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 28	-10.867	-10.867	0.000	-0.039	0.000	-0.039	20.952	0.000	90.000	11.137	11.137	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000

-3.712 Weight of Soil Load (Typ.)
11.137 Combined Weight of Soil and Arch (Typ.)

AM AN	AO AP R(1)	AQ AR R(1V)	AS AT R(1H)	AU AV FRIC(1)	AW AX FRIC(1V)	AY AZ FRIC(1H)	BA BB Load(H)	BC BD R(2)	BE BF R(2V)	BG BH R(2H)	BI BJ FRIC(2)	BK BL FRIC(2V)	BM BN FRIC(2H)	BO BP M(cgH)	BQ BR SIN ALPHA 1	BS BT COS ALPHA 1	BU BV SIN ALPHA 2	BW BX COS ALPHA 2
BLOCK 1	-2.315	0.000	2.315	0.000	0.000	0.000	0.000	2.313	0.101	-2.311	-0.101	-0.101	-0.004	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-2.313	-0.101	2.311	0.101	0.101	0.004	-0.000	2.321	0.303	-2.301	-0.102	-0.101	-0.013	-1.130	0.044	0.999	0.131	0.991
BLOCK 3	-2.321	-0.303	2.301	0.102	0.101	0.013	-0.001	2.346	0.508	-2.290	-0.106	-0.104	-0.023	-2.299	0.131	0.991	0.216	0.976
BLOCK 4	-2.346	-0.508	2.290	0.106	0.104	0.023	-0.004	2.386	0.718	-2.276	-0.111	-0.106	-0.033	-3.548	0.216	0.976	0.301	0.954
BLOCK 5	-2.386	-0.718	2.276	0.111	0.106	0.033	-0.009	2.441	0.934	-2.255	-0.119	-0.110	-0.046	-4.917	0.301	0.954	0.383	0.924
BLOCK 6	-2.441	-0.934	2.255	0.119	0.110	0.046	-0.016	2.508	1.158	-2.225	-0.129	-0.114	-0.059	-6.450	0.383	0.924	0.462	0.887
BLOCK 7	-2.508	-1.158	2.225	0.129	0.114	0.059	-0.027	2.588	1.390	-2.182	-0.140	-0.118	-0.075	-8.188	0.462	0.887	0.537	0.843
BLOCK 8	-2.588	-1.390	2.182	0.140	0.118	0.075	-0.041	2.677	1.630	-2.124	-0.153	-0.121	-0.093	-10.169	0.537	0.843	0.609	0.793
BLOCK 9	-2.677	-1.630	2.124	0.153	0.121	0.093	-0.058	2.775	1.875	-2.046	-0.168	-0.124	-0.113	-12.422	0.609	0.793	0.676	0.737
BLOCK 10	-2.775	-1.875	2.046	0.168	0.124	0.113	-0.079	2.879	2.122	-1.945	-0.184	-0.124	-0.136	-14.967	0.676	0.737	0.737	0.676
BLOCK 11	-2.879	-2.122	1.945	0.184	0.124	0.136	-0.103	2.986	2.369	-1.818	-0.201	-0.123	-0.160	-17.811	0.737	0.676	0.793	0.609
BLOCK 12	-2.986	-2.369	1.818	0.201	0.123	0.160	-0.130	3.094	2.610	-1.662	-0.219	-0.118	-0.185	-20.943	0.793	0.609	0.843	0.537
BLOCK 13	-3.094	-2.610	1.662	0.219	0.118	0.185	-0.160	3.198	2.837	-1.477	-0.237	-0.110	-0.211	-24.334	0.843	0.537	0.887	0.462
BLOCK 14	-3.198	-2.837	1.477	0.237	0.110	0.211	-0.192	3.295	3.044	-1.261	-0.254	-0.097	-0.235	-27.929	0.887	0.462	0.924	0.383
BLOCK 15	-3.295	-3.044	1.261	0.254	0.097	0.235	-0.226	3.377	3.221	-1.016	-0.266	-0.080	-0.254	-31.642	0.924	0.383	0.954	0.301
BLOCK 16	-3.377	-3.221	1.016	0.266	0.080	0.254	-0.260	3.442	3.360	-0.745	-0.271	-0.059	-0.265	-35.346	0.954	0.301	0.976	0.216
BLOCK 17	-3.442	-3.360	0.745	0.271	0.059	0.265	-0.294	3.483	3.453	-0.455	-0.263	-0.034	-0.261	-38.859	0.976	0.216	0.991	0.131
BLOCK 18	-3.483	-3.453	0.455	0.263	0.034	0.261	-0.327	3.501	3.498	-0.153	-0.236	-0.010	-0.236	-41.934	0.991	0.131	0.999	0.044
BLOCK 19	-3.501	-3.498	0.153	0.236	0.010	0.236	-0.359	3.508	3.508	0.000	-0.030	0.000	-0.030	-43.528	0.999	0.044	1.000	0.000
BLOCK 20	-3.508	-3.508	0.000	0.030	0.000	0.030	-0.389	3.508	3.508	0.000	0.359	0.000	0.359	-41.554	1.000	0.000	1.000	0.000
BLOCK 21	-3.508	-3.508	0.000	-0.359	0.000	-0.359	-0.419	3.508	3.508	0.000	0.777	0.000	0.777	-34.737	1.000	0.000	1.000	0.000
BLOCK 22	-3.508	-3.508	0.000	-0.777	0.000	-0.777	-0.449	3.508	3.508	0.000	1.226	0.000	1.226	-22.718	1.000	0.000	1.000	0.000
BLOCK 23	-3.508	-3.508	0.000	-1.226	0.000	-1.226	-0.479	3.508	3.508	0.000	1.704	0.000	1.704	-5.136	1.000	0.000	1.000	0.000
BLOCK 24	-3.508	-3.508	0.000	-1.704	0.000	-1.704	-0.509	3.508	3.508	0.000	2.213	0.000	2.213	18.369	1.000	0.000	1.000	0.000
BLOCK 25	-3.508	-3.508	0.000	-2.213	0.000	-2.213	-0.539	3.508	3.508	0.000	2.752	0.000	2.752	48.156	1.000	0.000	1.000	0.000
BLOCK 26	-3.508	-3.508	0.000	-2.752	0.000	-2.752	-0.569	3.508	3.508	0.000	3.320	0.000	3.320	84.586	1.000	0.000	1.000	0.000
BLOCK 27	-3.508	-3.508	0.000	-3.320	0.000	-3.320	-0.599	3.508	3.508	0.000	3.919	0.000	3.919	128.019	1.000	0.000	1.000	0.000
BLOCK 28	-3.508	-3.508	0.000	-3.919	0.000	-3.919	-0.629	3.508	3.508	0.000	4.547	0.000	4.547	178.814	1.000	0.000	1.000	0.000

-6.862 Total Lateral Load from Soil (Typ.)

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-5.410	0.000	0.000	0.000	5.408	0.000	-0.033			0.000	0.000	
BLOCK 2	-5.408	0.000	0.033	1.318	5.504	0.239	-0.610			1.318	0.239	
BLOCK 3	-5.504	0.239	0.610	3.205	5.655	0.573	-0.148			1.887	0.334	
BLOCK 4	-5.655	0.573	0.148	3.665	5.866	0.652	-0.375			0.460	0.078	
BLOCK 5	-5.866	0.652	0.375	4.004	6.135	0.707	-0.157			0.338	0.055	
BLOCK 6	-6.135	0.707	0.157	3.644	6.457	0.651	-0.291			-0.359	-0.056	
BLOCK 7	-6.457	0.651	0.291	2.894	6.829	0.541	-0.138			-0.750	-0.110	
BLOCK 8	-6.829	0.541	0.138	1.471	7.244	0.345	-0.231			-1.423	-0.196	
BLOCK 9	-7.244	0.345	0.231	-0.509	7.698	0.088	-0.107			-1.980	-0.257	
BLOCK 10	-7.698	0.088	0.107	-3.209	8.183	-0.242	-0.177			-2.700	-0.330	
BLOCK 11	-8.183	-0.242	0.177	-6.566	8.691	-0.629	-0.068			-3.357	-0.386	
BLOCK 12	-8.691	-0.629	0.068	-10.664	9.213	-1.073	-0.125			-4.098	-0.445	
BLOCK 13	-9.213	-1.073	0.125	-15.439	9.737	-1.564	-0.025			-4.775	-0.490	
BLOCK 14	-9.737	-1.564	0.025	-20.899	10.253	-2.096	-0.072			-5.459	-0.532	
BLOCK 15	-10.253	-2.096	0.072	-26.936	10.745	-2.658	0.026			-6.038	-0.562	
BLOCK 16	-10.745	-2.658	-0.026	-33.456	11.201	-3.240	-0.008			-6.520	-0.582	
BLOCK 17	-11.201	-3.240	0.008	-40.254	11.605	-3.826	0.102			-6.798	-0.586	
BLOCK 18	-11.605	-3.826	-0.102	-47.073	11.946	-4.397	0.094			-6.820	-0.571	
BLOCK 19	-11.946	-4.397	-0.094	-50.879	12.215	-4.708	0.009			-3.806	-0.312	
BLOCK 20	-12.215	-4.708	-0.009	-48.905	12.485	-4.550	0.320	0.026	1.469	1.974	0.158	0.307
BLOCK 21	-12.485	-4.550	-0.320	-42.089	12.755	-4.016	0.816	0.064	3.660	6.817	0.534	1.072
BLOCK 22	-12.755	-4.016	-0.816	-30.069	13.025	-3.093	1.187	0.091	5.208	12.019	0.923	2.157
BLOCK 23	-13.025	-3.093	-1.187	-12.487	13.295	-1.771	1.743	0.131	7.469	17.582	1.322	3.703
BLOCK 24	-13.295	-1.771	-1.743	11.017	13.565	-0.038	2.174	0.160	9.106	23.505	1.733	5.579
BLOCK 25	-13.565	-0.038	-2.174	40.805	13.835	2.115	2.790	0.202	11.402	29.787	2.153	7.904
BLOCK 26	-13.835	2.115	-2.790	77.235	14.105	4.698	3.281	0.233	13.096	36.430	2.583	10.553
BLOCK 27	-14.105	4.698	-3.281	120.667	14.375	7.719	3.957	0.275	15.391	43.433	3.021	13.623
BLOCK 28	-14.375	7.719	-3.957	171.463	14.645	11.187	4.509	0.308	17.111	50.795	3.468	16.998

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH3-DISC1
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=3.0 FEET
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL 3 FEET ABOVE ARCH

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-7.222	0.000	7.222	0.000	0.000	0.000	3.000	-0.180	0.000	7.222	0.315	-7.215	0.158	0.157	0.007	0.000	0.000	2.500
BLOCK 2	-7.222	-0.315	7.215	-0.158	-0.157	-0.007	3.087	-0.369	5.000	7.309	0.954	-7.247	-0.298	-0.296	-0.039	0.812	2.500	7.500
BLOCK 3	-7.309	-0.954	7.247	0.298	0.296	0.039	3.261	-0.385	10.000	7.436	1.609	-7.260	0.121	0.118	0.026	1.864	7.500	12.500
BLOCK 4	-7.436	-1.609	7.260	-0.121	-0.118	-0.026	3.520	-0.408	15.000	7.607	2.287	-7.255	-0.070	-0.067	-0.021	1.691	12.500	17.500
BLOCK 5	-7.607	-2.287	7.255	0.070	0.067	0.021	3.862	-0.435	20.000	7.821	2.993	-7.225	0.132	0.122	0.050	1.499	17.500	22.500
BLOCK 6	-7.821	-2.993	7.225	-0.132	-0.122	-0.050	4.284	-0.466	25.000	8.075	3.729	-7.163	0.026	0.023	0.012	0.820	22.500	27.500
BLOCK 7	-8.075	-3.729	7.163	-0.026	-0.023	-0.012	4.784	-0.497	30.000	8.368	4.496	-7.057	0.174	0.147	0.094	-0.043	27.500	32.500
BLOCK 8	-8.368	-4.496	7.057	-0.174	-0.147	-0.094	5.358	-0.527	35.000	8.694	5.293	-6.897	0.109	0.086	0.066	-1.311	32.500	37.500
BLOCK 9	-8.694	-5.293	6.897	-0.109	-0.086	-0.066	6.001	-0.552	40.000	9.050	6.114	-6.673	0.235	0.173	0.159	-2.864	37.500	42.500
BLOCK 10	-9.050	-6.114	6.673	-0.235	-0.173	-0.159	6.708	-0.569	45.000	9.431	6.953	-6.372	0.193	0.130	0.142	-4.836	42.500	47.500
BLOCK 11	-9.431	-6.953	6.372	-0.193	-0.130	-0.142	7.474	-0.576	50.000	9.832	7.800	-5.985	0.308	0.188	0.245	-7.174	47.500	52.500
BLOCK 12	-9.832	-7.800	5.985	-0.308	-0.188	-0.245	8.293	-0.571	55.000	10.245	8.641	-5.505	0.280	0.150	0.236	-9.969	52.500	57.500
BLOCK 13	-10.245	-8.641	5.505	-0.280	-0.150	-0.236	9.159	-0.550	60.000	10.665	9.460	-4.925	0.388	0.179	0.344	-13.198	57.500	62.500
BLOCK 14	-10.665	-9.460	4.925	-0.388	-0.179	-0.344	10.065	-0.510	65.000	11.084	10.241	-4.242	0.367	0.140	0.339	-16.924	62.500	67.500
BLOCK 15	-11.084	-10.241	4.242	-0.367	-0.140	-0.339	11.005	-0.452	70.000	11.494	10.962	-3.456	0.468	0.141	0.447	-21.133	67.500	72.500
BLOCK 16	-11.494	-10.962	3.456	-0.468	-0.141	-0.447	11.971	-0.372	75.000	11.886	11.604	-2.573	0.448	0.097	0.437	-25.859	72.500	77.500
BLOCK 17	-11.886	-11.604	2.573	-0.448	-0.097	-0.437	12.956	-0.270	80.000	12.249	12.144	-1.599	0.541	0.071	0.537	-31.082	77.500	82.500
BLOCK 18	-12.249	-12.144	1.599	-0.541	-0.071	-0.537	13.952	-0.146	85.000	12.572	12.560	-0.548	0.514	0.022	0.514	-36.795	82.500	87.500
BLOCK 19	-12.572	-12.560	0.548	-0.514	-0.022	-0.514	14.952	0.000	90.000	12.830	12.830	0.000	0.035	0.000	0.035	-40.088	87.500	90.000
BLOCK 20	-12.830	-12.830	0.000	-0.035	0.000	-0.035	15.952	0.000	90.000	13.100	13.100	0.000	-0.035	0.000	-0.035	-40.088	90.000	90.000
BLOCK 21	-13.100	-13.100	0.000	0.035	0.000	0.035	16.952	0.000	90.000	13.370	13.370	0.000	0.035	0.000	0.035	-40.088	90.000	90.000
BLOCK 22	-13.370	-13.370	0.000	-0.035	0.000	-0.035	17.952	0.000	90.000	13.640	13.640	0.000	-0.035	0.000	-0.035	-40.088	90.000	90.000
BLOCK 23	-13.640	-13.640	0.000	0.035	0.000	0.035	18.952	0.000	90.000	13.910	13.910	0.000	0.035	0.000	0.035	-40.088	90.000	90.000
BLOCK 24	-13.910	-13.910	0.000	-0.035	0.000	-0.035	19.952	0.000	90.000	14.180	14.180	0.000	-0.035	0.000	-0.035	-40.088	90.000	90.000
BLOCK 25	-14.180	-14.180	0.000	0.035	0.000	0.035	20.952	0.000	90.000	14.450	14.450	0.000	0.035	0.000	0.035	-40.088	90.000	90.000
BLOCK 26	-14.450	-14.450	0.000	-0.035	0.000	-0.035	21.952	0.000	90.000	14.720	14.720	0.000	-0.035	0.000	-0.035	-40.088	90.000	90.000
BLOCK 27	-14.720	-14.720	0.000	0.035	0.000	0.035	22.952	0.000	90.000	14.990	14.990	0.000	0.035	0.000	0.035	-40.088	90.000	90.000
BLOCK 28	-14.990	-14.990	0.000	-0.035	0.000	-0.035	23.952	0.000	90.000	15.260	15.260	0.000	-0.035	0.000	-0.035	-40.088	90.000	90.000

-7.835
15.260

AM AN	AO AP	AQ AR	AS AT	AU AV	AW AX	AY AZ	BA BB	BC BD	BE BF	BG BH	BI BJ	BK BL	BM BN	BO BP	BQ BR	BS BT	BU BV	BW BX
	R(1)	R(1V)	R(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	Load(H)	R(2)	R(2V)	R(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgH)	SIN ALPHA 1	COS ALPHA 1	SIN ALPHA 2	COS ALPHA 2
BLOCK 1	-3.315	0.000	3.315	0.000	0.000	0.000	0.000	3.312	0.144	-3.309	-0.145	-0.144	-0.006	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-3.312	-0.144	3.309	0.145	0.144	0.006	-0.008	3.316	0.433	-3.288	-0.145	-0.144	-0.019	-1.694	0.044	0.999	0.131	0.991
BLOCK 3	-3.316	-0.433	3.288	0.145	0.144	0.019	-0.017	3.337	0.722	-3.258	-0.149	-0.145	-0.032	-3.505	0.131	0.991	0.216	0.976
BLOCK 4	-3.337	-0.722	3.258	0.149	0.145	0.032	-0.027	3.373	1.014	-3.216	-0.154	-0.147	-0.046	-5.467	0.216	0.976	0.301	0.954
BLOCK 5	-3.373	-1.014	3.216	0.154	0.147	0.046	-0.040	3.422	1.309	-3.161	-0.161	-0.149	-0.062	-7.612	0.301	0.954	0.383	0.924
BLOCK 6	-3.422	-1.309	3.161	0.161	0.149	0.062	-0.054	3.484	1.609	-3.090	-0.170	-0.150	-0.078	-9.973	0.383	0.924	0.462	0.887
BLOCK 7	-3.484	-1.609	3.090	0.170	0.150	0.078	-0.072	3.557	1.911	-3.000	-0.180	-0.152	-0.097	-12.579	0.462	0.887	0.537	0.843
BLOCK 8	-3.557	-1.911	3.000	0.180	0.152	0.097	-0.092	3.640	2.216	-2.888	-0.192	-0.153	-0.117	-15.454	0.537	0.843	0.609	0.793
BLOCK 9	-3.640	-2.216	2.888	0.192	0.153	0.117	-0.116	3.730	2.520	-2.750	-0.206	-0.152	-0.139	-18.610	0.609	0.793	0.676	0.737
BLOCK 10	-3.730	-2.520	2.750	0.206	0.152	0.139	-0.142	3.825	2.820	-2.584	-0.220	-0.149	-0.162	-22.049	0.676	0.737	0.737	0.676
BLOCK 11	-3.825	-2.820	2.584	0.220	0.149	0.162	-0.172	3.923	3.112	-2.388	-0.235	-0.143	-0.187	-25.758	0.737	0.676	0.793	0.609
BLOCK 12	-3.923	-3.112	2.388	0.235	0.143	0.187	-0.204	4.020	3.390	-2.160	-0.251	-0.135	-0.211	-29.704	0.793	0.609	0.843	0.537
BLOCK 13	-4.020	-3.390	2.160	0.251	0.135	0.211	-0.238	4.112	3.647	-1.899	-0.265	-0.122	-0.235	-33.835	0.843	0.537	0.887	0.462
BLOCK 14	-4.112	-3.647	1.899	0.265	0.122	0.235	-0.274	4.194	3.875	-1.605	-0.276	-0.105	-0.255	-38.069	0.887	0.462	0.924	0.383
BLOCK 15	-4.194	-3.875	1.605	0.276	0.105	0.255	-0.310	4.262	4.065	-1.282	-0.281	-0.084	-0.268	-42.291	0.924	0.383	0.954	0.301
BLOCK 16	-4.262	-4.065	1.282	0.281	0.084	0.268	-0.347	4.311	4.209	-0.933	-0.276	-0.060	-0.269	-46.340	0.954	0.301	0.976	0.216
BLOCK 17	-4.311	-4.209	0.933	0.276	0.060	0.269	-0.383	4.339	4.302	-0.566	-0.255	-0.033	-0.253	-50.000	0.976	0.216	0.991	0.131
BLOCK 18	-4.339	-4.302	0.566	0.255	0.033	0.253	-0.417	4.349	4.344	-0.190	-0.213	-0.009	-0.213	-52.989	0.991	0.131	0.999	0.044
BLOCK 19	-4.349	-4.344	0.190	0.213	0.009	0.213	-0.449	4.354	4.354	0.000	0.046	0.000	0.046	-53.993	0.999	0.044	1.000	0.000
BLOCK 20	-4.354	-4.354	0.000	-0.046	0.000	-0.046	-0.479	4.354	4.354	0.000	0.524	0.000	0.524	-50.571	1.000	0.000	1.000	0.000
BLOCK 21	-4.354	-4.354	0.000	-0.524	0.000	-0.524	-0.509	4.354	4.354	0.000	1.033	0.000	1.033	-41.226	1.000	0.000	1.000	0.000
BLOCK 22	-4.354	-4.354	0.000	-1.033	0.000	-1.033	-0.539	4.354	4.354	0.000	1.572	0.000	1.572	-25.599	1.000	0.000	1.000	0.000
BLOCK 23	-4.354	-4.354	0.000	-1.572	0.000	-1.572	-0.569	4.354	4.354	0.000	2.140	0.000	2.140	-3.329	1.000	0.000	1.000	0.000
BLOCK 24	-4.354	-4.354	0.000	-2.140	0.000	-2.140	-0.599	4.354	4.354	0.000	2.739	0.000	2.739	25.944	1.000	0.000	1.000	0.000
BLOCK 25	-4.354	-4.354	0.000	-2.739	0.000	-2.739	-0.629	4.354	4.354	0.000	3.367	0.000	3.367	62.579	1.000	0.000	1.000	0.000
BLOCK 26	-4.354	-4.354	0.000	-3.367	0.000	-3.367	-0.659	4.354	4.354	0.000	4.026	0.000	4.026	106.937	1.000	0.000	1.000	0.000
BLOCK 27	-4.354	-4.354	0.000	-4.026	0.000	-4.026	-0.689	4.354	4.354	0.000	4.714	0.000	4.714	159.378	1.000	0.000	1.000	0.000
BLOCK 28	-4.354	-4.354	0.000	-4.714	0.000	-4.714	-0.719	4.354	4.354	0.000	5.433	0.000	5.433	220.261	1.000	0.000	1.000	0.000
							-8.748											

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-10.537	0.000	0.000	0.000	10.533	0.000	0.013			0.000	0.000	
BLOCK 2	-10.533	0.000	-0.013	-0.882	10.626	-0.083	-0.443			-0.882	-0.083	
BLOCK 3	-10.626	-0.083	0.443	-1.641	10.773	-0.153	-0.028			-0.759	-0.070	
BLOCK 4	-10.773	-0.153	0.028	-3.776	10.979	-0.348	-0.224			-2.135	-0.194	
BLOCK 5	-10.979	-0.348	0.224	-6.113	11.242	-0.556	-0.029			-2.337	-0.208	
BLOCK 6	-11.242	-0.556	0.029	-9.153	11.559	-0.819	-0.144			-3.040	-0.263	
BLOCK 7	-11.559	-0.819	0.144	-12.622	11.925	-1.110	-0.006			-3.469	-0.291	
BLOCK 8	-11.925	-1.110	0.006	-16.765	12.334	-1.446	-0.084			-4.143	-0.336	
BLOCK 9	-12.334	-1.446	0.084	-21.474	12.780	-1.814	0.029			-4.709	-0.368	
BLOCK 10	-12.780	-1.814	-0.029	-26.885	13.257	-2.222	-0.028			-5.411	-0.408	
BLOCK 11	-13.257	-2.222	0.028	-32.932	13.755	-2.662	0.073			-6.047	-0.440	
BLOCK 12	-13.755	-2.662	-0.073	-39.673	14.265	-3.134	0.029			-6.741	-0.473	
BLOCK 13	-14.265	-3.134	-0.029	-47.033	14.777	-3.633	0.124			-7.360	-0.498	
BLOCK 14	-14.777	-3.633	-0.124	-54.993	15.278	-4.153	0.091			-7.959	-0.521	
BLOCK 15	-15.278	-4.153	-0.091	-63.424	15.756	-4.689	0.188			-8.432	-0.535	
BLOCK 16	-15.756	-4.689	-0.188	-72.199	16.197	-5.230	0.172			-8.775	-0.542	
BLOCK 17	-16.197	-5.230	-0.172	-81.082	16.588	-5.766	0.286			-8.883	-0.536	
BLOCK 18	-16.588	-5.766	-0.286	-89.784	16.921	-6.280	0.301			-8.703	-0.514	
BLOCK 19	-16.921	-6.280	-0.301	-94.081	17.184	-6.530	0.081			-4.297	-0.250	
BLOCK 20	-17.184	-6.530	-0.081	-90.659	17.454	-6.334	0.490	0.028	1.607	3.422	0.196	0.336
BLOCK 21	-17.454	-6.334	-0.490	-81.315	17.724	-5.807	1.068	0.060	3.447	9.345	0.527	1.057
BLOCK 22	-17.724	-5.807	-1.068	-65.687	17.994	-4.938	1.537	0.085	4.882	15.627	0.868	2.074
BLOCK 23	-17.994	-4.938	-1.537	-43.417	18.264	-3.719	2.175	0.119	6.791	22.270	1.219	3.483
BLOCK 24	-18.264	-3.719	-2.175	-14.145	18.534	-2.140	2.704	0.146	8.301	29.273	1.579	5.197
BLOCK 25	-18.534	-2.140	-2.704	22.491	18.804	-0.191	3.402	0.181	10.255	36.635	1.948	7.300
BLOCK 26	-18.804	-0.191	-3.402	66.849	19.074	2.134	3.991	0.209	11.818	44.358	2.326	9.705
BLOCK 27	-19.074	2.134	-3.991	119.290	19.344	4.845	4.749	0.246	13.794	52.441	2.711	12.484
BLOCK 28	-19.344	4.845	-4.749	180.173	19.614	7.949	5.398	0.275	15.388	60.883	3.104	15.554

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH5-DISC2
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGTHH H=5.0 FEET
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-9.973	0.000	9.973	0.000	0.000	0.000	5.000	-0.300	0.000	9.973	0.435	-9.963	0.218	0.217	0.009	0.000	0.000	2.500
BLOCK 2	-9.973	-0.435	9.963	-0.218	-0.217	-0.009	5.087	-0.608	5.000	10.060	1.313	-9.974	-0.158	-0.157	-0.021	-0.278	2.500	7.500
BLOCK 3	-10.060	-1.313	9.974	0.158	0.157	0.021	5.261	-0.622	10.000	10.187	2.205	-9.945	0.229	0.223	0.049	-0.563	7.500	12.500
BLOCK 4	-10.187	-2.205	9.945	-0.229	-0.223	-0.049	5.520	-0.640	15.000	10.358	3.115	-9.878	0.059	0.056	0.018	-1.990	12.500	17.500
BLOCK 5	-10.358	-3.115	9.878	-0.059	-0.056	-0.018	5.862	-0.661	20.000	10.572	4.046	-9.767	0.245	0.226	0.094	-3.449	17.500	22.500
BLOCK 6	-10.572	-4.046	9.767	-0.245	-0.226	-0.094	6.284	-0.683	25.000	10.826	4.999	-9.603	0.152	0.135	0.070	-5.362	22.500	27.500
BLOCK 7	-10.826	-4.999	9.603	-0.152	-0.135	-0.070	6.784	-0.705	30.000	11.119	5.974	-9.377	0.290	0.244	0.156	-7.459	27.500	32.500
BLOCK 8	-11.119	-5.974	9.377	-0.290	-0.244	-0.156	7.358	-0.723	35.000	11.445	6.967	-9.080	0.233	0.185	0.142	-9.944	32.500	37.500
BLOCK 9	-11.445	-6.967	9.080	-0.233	-0.185	-0.142	8.001	-0.735	40.000	11.801	7.973	-8.701	0.351	0.259	0.237	-12.715	37.500	42.500
BLOCK 10	-11.801	-7.973	8.701	-0.351	-0.259	-0.237	8.708	-0.739	45.000	12.182	8.982	-8.230	0.316	0.214	0.233	-15.898	42.500	47.500
BLOCK 11	-12.182	-8.982	8.230	-0.316	-0.214	-0.233	9.474	-0.731	50.000	12.583	9.982	-7.660	0.425	0.259	0.337	-19.453	47.500	52.500
BLOCK 12	-12.583	-9.982	7.660	-0.425	-0.259	-0.337	10.293	-0.708	55.000	12.996	10.961	-6.983	0.403	0.216	0.340	-23.467	52.500	57.500
BLOCK 13	-12.996	-10.961	6.983	-0.403	-0.216	-0.340	11.159	-0.670	60.000	13.416	11.900	-6.195	0.505	0.233	0.448	-27.927	57.500	62.500
BLOCK 14	-13.416	-11.900	6.195	-0.505	-0.233	-0.448	12.065	-0.612	65.000	13.835	12.782	-5.295	0.489	0.187	0.452	-32.893	62.500	67.500
BLOCK 15	-13.835	-12.782	5.295	-0.489	-0.187	-0.452	13.005	-0.534	70.000	14.245	13.586	-4.284	0.586	0.176	0.559	-38.360	67.500	72.500
BLOCK 16	-14.245	-13.586	4.284	-0.586	-0.176	-0.559	13.971	-0.434	75.000	14.637	14.290	-3.168	0.570	0.123	0.557	-44.358	72.500	77.500
BLOCK 17	-14.637	-14.290	3.168	-0.570	-0.123	-0.557	14.956	-0.312	80.000	15.000	14.872	-1.958	0.659	0.086	0.653	-50.873	77.500	82.500
BLOCK 18	-15.000	-14.872	1.958	-0.659	-0.086	-0.653	15.952	-0.167	85.000	15.323	15.308	-0.668	0.637	0.028	0.636	-57.899	82.500	87.500
BLOCK 19	-15.323	-15.308	0.668	-0.637	-0.028	-0.636	16.952	0.000	90.000	15.578	15.578	0.000	0.032	0.000	0.032	-61.913	87.500	90.000
BLOCK 20	-15.578	-15.578	0.000	-0.032	0.000	-0.032	17.952	0.000	90.000	15.848	15.848	0.000	-0.032	0.000	-0.032	-61.913	90.000	90.000
BLOCK 21	-15.848	-15.848	0.000	0.032	0.000	0.032	18.952	0.000	90.000	16.118	16.118	0.000	0.032	0.000	0.032	-61.913	90.000	90.000
BLOCK 22	-16.118	-16.118	0.000	-0.032	0.000	-0.032	19.952	0.000	90.000	16.388	16.388	0.000	-0.032	0.000	-0.032	-61.913	90.000	90.000
BLOCK 23	-16.388	-16.388	0.000	0.032	0.000	0.032	20.952	0.000	90.000	16.658	16.658	0.000	0.032	0.000	0.032	-61.913	90.000	90.000
BLOCK 24	-16.658	-16.658	0.000	-0.032	0.000	-0.032	21.952	0.000	90.000	16.928	16.928	0.000	-0.032	0.000	-0.032	-61.913	90.000	90.000
BLOCK 25	-16.928	-16.928	0.000	0.032	0.000	0.032	22.952	0.000	90.000	17.198	17.198	0.000	0.032	0.000	0.032	-61.913	90.000	90.000
BLOCK 26	-17.198	-17.198	0.000	-0.032	0.000	-0.032	23.952	0.000	90.000	17.468	17.468	0.000	-0.032	0.000	-0.032	-61.913	90.000	90.000
BLOCK 27	-17.468	-17.468	0.000	0.032	0.000	0.032	24.952	0.000	90.000	17.738	17.738	0.000	0.032	0.000	0.032	-61.913	90.000	90.000
BLOCK 28	-17.738	-17.738	0.000	-0.032	0.000	-0.032	25.952	0.000	90.000	18.008	18.008	0.000	-0.032	0.000	-0.032	-61.913	90.000	90.000

-10.583
18.008

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

FILL 5 FEET ABOVE ARCH

AM AN	AO AP	AQ AR	AS AT	AU AV	AW AX	AY AZ	BA BB	BC BD	BE BF	BG BH	BI BJ	BK BL	BM BN	BO BP	BQ BR	BS BT	BU BV	BW BX
	R(1)	R(1V)	R(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	Load(H)	R(2)	R(2V)	R(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgH)	SIN ALPHA 1	COS ALPHA 1	SIN ALPHA 2	COS ALPHA 2
BLOCK 1	-3.955	0.000	3.955	0.000	0.000	0.000	0.000	3.951	0.172	-3.947	-0.173	-0.172	-0.008	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-3.951	-0.172	3.947	0.173	0.172	0.008	-0.013	3.953	0.516	-3.919	-0.173	-0.171	-0.023	-2.058	0.044	0.999	0.131	0.991
BLOCK 3	-3.953	-0.516	3.919	0.173	0.171	0.023	-0.027	3.970	0.859	-3.876	-0.176	-0.172	-0.038	-4.283	0.131	0.991	0.216	0.976
BLOCK 4	-3.970	-0.859	3.876	0.176	0.172	0.038	-0.043	4.002	1.204	-3.817	-0.180	-0.172	-0.054	-6.706	0.216	0.976	0.301	0.954
BLOCK 5	-4.002	-1.204	3.817	0.180	0.172	0.054	-0.060	4.048	1.549	-3.740	-0.188	-0.173	-0.072	-9.353	0.301	0.954	0.383	0.924
BLOCK 6	-4.048	-1.549	3.740	0.188	0.173	0.072	-0.080	4.105	1.896	-3.641	-0.195	-0.173	-0.090	-12.250	0.383	0.924	0.462	0.887
BLOCK 7	-4.105	-1.896	3.641	0.195	0.173	0.090	-0.102	4.173	2.242	-3.519	-0.205	-0.173	-0.110	-15.417	0.462	0.887	0.537	0.843
BLOCK 8	-4.173	-2.242	3.519	0.205	0.173	0.110	-0.127	4.250	2.587	-3.372	-0.216	-0.172	-0.132	-18.866	0.537	0.843	0.609	0.793
BLOCK 9	-4.250	-2.587	3.372	0.216	0.172	0.132	-0.154	4.333	2.927	-3.195	-0.229	-0.169	-0.154	-22.599	0.609	0.793	0.676	0.737
BLOCK 10	-4.333	-2.927	3.195	0.229	0.169	0.154	-0.185	4.420	3.259	-2.986	-0.241	-0.163	-0.178	-26.604	0.676	0.737	0.737	0.676
BLOCK 11	-4.420	-3.259	2.986	0.241	0.163	0.178	-0.218	4.509	3.577	-2.745	-0.254	-0.155	-0.202	-30.853	0.737	0.676	0.793	0.609
BLOCK 12	-4.509	-3.577	2.745	0.254	0.155	0.202	-0.253	4.595	3.875	-2.469	-0.267	-0.143	-0.225	-35.295	0.793	0.609	0.843	0.537
BLOCK 13	-4.595	-3.875	2.469	0.267	0.143	0.225	-0.290	4.674	4.146	-2.158	-0.277	-0.128	-0.245	-39.860	0.843	0.537	0.887	0.462
BLOCK 14	-4.674	-4.146	2.158	0.277	0.128	0.245	-0.328	4.743	4.382	-1.815	-0.282	-0.108	-0.261	-44.443	0.887	0.462	0.924	0.383
BLOCK 15	-4.743	-4.382	1.815	0.282	0.108	0.261	-0.367	4.796	4.574	-1.442	-0.280	-0.084	-0.267	-48.902	0.924	0.383	0.954	0.301
BLOCK 16	-4.796	-4.574	1.442	0.280	0.084	0.267	-0.405	4.830	4.715	-1.045	-0.265	-0.057	-0.259	-53.046	0.954	0.301	0.976	0.216
BLOCK 17	-4.830	-4.715	1.045	0.265	0.057	0.259	-0.442	4.844	4.803	-0.632	-0.232	-0.030	-0.230	-56.625	0.976	0.216	0.991	0.131
BLOCK 18	-4.844	-4.803	0.632	0.232	0.030	0.230	-0.477	4.845	4.841	-0.211	-0.174	-0.008	-0.174	-59.324	0.991	0.131	0.999	0.044
BLOCK 19	-4.845	-4.841	0.211	0.174	0.008	0.174	-0.509	4.848	4.848	0.000	0.123	0.000	0.123	-59.632	0.999	0.044	1.000	0.000
BLOCK 20	-4.848	-4.848	0.000	-0.123	0.000	-0.123	-0.539	4.848	4.848	0.000	0.662	0.000	0.662	-54.925	1.000	0.000	1.000	0.000
BLOCK 21	-4.848	-4.848	0.000	-0.662	0.000	-0.662	-0.569	4.848	4.848	0.000	1.230	0.000	1.230	-43.575	1.000	0.000	1.000	0.000
BLOCK 22	-4.848	-4.848	0.000	-1.230	0.000	-1.230	-0.599	4.848	4.848	0.000	1.829	0.000	1.829	-25.222	1.000	0.000	1.000	0.000
BLOCK 23	-4.848	-4.848	0.000	-1.829	0.000	-1.829	-0.629	4.848	4.848	0.000	2.457	0.000	2.457	0.493	1.000	0.000	1.000	0.000
BLOCK 24	-4.848	-4.848	0.000	-2.457	0.000	-2.457	-0.659	4.848	4.848	0.000	3.116	0.000	3.116	33.931	1.000	0.000	1.000	0.000
BLOCK 25	-4.848	-4.848	0.000	-3.116	0.000	-3.116	-0.689	4.848	4.848	0.000	3.804	0.000	3.804	75.452	1.000	0.000	1.000	0.000
BLOCK 26	-4.848	-4.848	0.000	-3.804	0.000	-3.804	-0.719	4.848	4.848	0.000	4.523	0.000	4.523	125.415	1.000	0.000	1.000	0.000
BLOCK 27	-4.848	-4.848	0.000	-4.523	0.000	-4.523	-0.749	4.848	4.848	0.000	5.271	0.000	5.271	184.181	1.000	0.000	1.000	0.000
BLOCK 28	-4.848	-4.848	0.000	-5.271	0.000	-5.271	-0.779	4.848	4.848	0.000	6.050	0.000	6.050	252.110	1.000	0.000	1.000	0.000

-10.005

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-13.928	0.000	0.000	0.000	13.924	0.000	0.045			0.000	0.000	
BLOCK 2	-13.924	0.000	-0.045	-2.336	14.013	-0.167	-0.331			-2.336	-0.167	
BLOCK 3	-14.013	-0.167	0.331	-4.846	14.157	-0.344	0.052			-2.510	-0.177	
BLOCK 4	-14.157	-0.344	-0.052	-8.696	14.360	-0.612	-0.122			-3.850	-0.268	
BLOCK 5	-14.360	-0.612	0.122	-12.802	14.619	-0.893	0.058			-4.106	-0.281	
BLOCK 6	-14.619	-0.893	-0.058	-17.613	14.932	-1.215	-0.044			-4.811	-0.322	
BLOCK 7	-14.932	-1.215	0.044	-22.876	15.292	-1.559	0.084			-5.263	-0.344	
BLOCK 8	-15.292	-1.559	-0.084	-28.811	15.695	-1.937	0.017			-5.935	-0.378	
BLOCK 9	-15.695	-1.937	-0.017	-35.314	16.134	-2.341	0.123			-6.504	-0.403	
BLOCK 10	-16.134	-2.341	-0.123	-42.503	16.602	-2.774	0.075			-7.188	-0.433	
BLOCK 11	-16.602	-2.774	-0.075	-50.305	17.091	-3.230	0.171			-7.803	-0.457	
BLOCK 12	-17.091	-3.230	-0.171	-58.763	17.591	-3.711	0.136			-8.457	-0.481	
BLOCK 13	-17.591	-3.711	-0.136	-67.787	18.091	-4.210	0.229			-9.025	-0.499	
BLOCK 14	-18.091	-4.210	-0.229	-77.336	18.578	-4.724	0.207			-9.549	-0.514	
BLOCK 15	-18.578	-4.724	-0.207	-87.262	19.041	-5.245	0.306			-9.926	-0.521	
BLOCK 16	-19.041	-5.245	-0.306	-97.404	19.467	-5.766	0.305			-10.143	-0.521	
BLOCK 17	-19.467	-5.766	-0.305	-107.499	19.844	-6.275	0.427			-10.094	-0.509	
BLOCK 18	-19.844	-6.275	-0.427	-117.223	20.169	-6.757	0.463			-9.724	-0.482	
BLOCK 19	-20.169	-6.757	-0.463	-121.545	20.427	-6.968	0.155			-4.322	-0.212	
BLOCK 20	-20.427	-6.968	-0.155	-116.838	20.697	-6.741	0.629	0.030	1.742	4.707	0.227	0.365
BLOCK 21	-20.697	-6.741	-0.629	-105.488	20.967	-6.200	1.262	0.060	3.445	11.350	0.541	1.084
BLOCK 22	-20.967	-6.200	-1.262	-87.135	21.237	-5.335	1.797	0.085	4.836	18.353	0.864	2.092
BLOCK 23	-21.237	-5.335	-1.797	-61.420	21.507	-4.140	2.489	0.116	6.602	25.715	1.196	3.463
BLOCK 24	-21.507	-4.140	-2.489	-27.982	21.777	-2.604	3.084	0.142	8.060	33.438	1.535	5.129
BLOCK 25	-21.777	-2.604	-3.084	13.539	22.047	-0.721	3.836	0.174	9.871	41.521	1.883	7.156
BLOCK 26	-22.047	-0.721	-3.836	63.503	22.317	1.518	4.491	0.201	11.378	49.963	2.239	9.476
BLOCK 27	-22.317	1.518	-4.491	122.269	22.587	4.120	5.304	0.235	13.214	58.766	2.602	12.147
BLOCK 28	-22.587	4.120	-5.304	190.197	22.857	7.091	6.018	0.263	14.750	67.929	2.972	15.101

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH10-DISC2
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=10.0 FEET
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(coV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-16.850	0.000	16.850	0.000	0.000	0.000	10.000	-0.600	0.000	16.850	0.735	-16.834	0.368	0.367	0.016	0.000	0.000	2.500
BLOCK 2	-16.850	-0.735	16.834	-0.368	-0.367	-0.016	10.087	-1.206	5.000	16.938	2.211	-16.793	0.193	0.191	0.025	-3.004	2.500	7.500
BLOCK 3	-16.938	-2.211	16.793	-0.193	-0.191	-0.025	10.261	-1.213	10.000	17.065	3.693	-16.660	0.499	0.487	0.108	-6.630	7.500	12.500
BLOCK 4	-17.065	-3.693	16.660	-0.499	-0.487	-0.108	10.520	-1.219	15.000	17.235	5.183	-16.438	0.381	0.363	0.114	-11.193	12.500	17.500
BLOCK 5	-17.235	-5.183	16.438	-0.381	-0.363	-0.114	10.862	-1.225	20.000	17.449	6.678	-16.121	0.528	0.488	0.202	-15.818	17.500	22.500
BLOCK 6	-17.449	-6.678	16.121	-0.528	-0.488	-0.202	11.284	-1.227	25.000	17.704	8.175	-15.704	0.466	0.414	0.215	-20.819	22.500	27.500
BLOCK 7	-17.704	-8.175	15.704	-0.466	-0.414	-0.215	11.784	-1.225	30.000	17.996	9.669	-15.178	0.578	0.487	0.310	-26.000	27.500	32.500
BLOCK 8	-17.996	-9.669	15.178	-0.578	-0.487	-0.310	12.358	-1.215	35.000	18.323	11.154	-14.536	0.544	0.432	0.331	-31.529	32.500	37.500
BLOCK 9	-18.323	-11.154	14.536	-0.544	-0.432	-0.331	13.001	-1.195	40.000	18.679	12.619	-13.772	0.642	0.473	0.434	-37.343	37.500	42.500
BLOCK 10	-18.679	-12.619	13.772	-0.642	-0.473	-0.434	13.708	-1.163	45.000	19.060	14.052	-12.877	0.625	0.423	0.461	-43.555	42.500	47.500
BLOCK 11	-19.060	-14.052	12.877	-0.625	-0.423	-0.461	14.474	-1.116	50.000	19.460	15.439	-11.847	0.717	0.437	0.569	-50.151	47.500	52.500
BLOCK 12	-19.460	-15.439	11.847	-0.717	-0.437	-0.569	15.293	-1.053	55.000	19.874	16.761	-10.678	0.711	0.382	0.600	-57.214	52.500	57.500
BLOCK 13	-19.874	-16.761	10.678	-0.711	-0.382	-0.600	16.159	-0.970	60.000	20.294	18.001	-9.371	0.798	0.369	0.708	-64.749	57.500	62.500
BLOCK 14	-20.294	-18.001	9.371	-0.798	-0.369	-0.708	17.065	-0.865	65.000	20.713	19.136	-7.927	0.797	0.305	0.736	-72.817	62.500	67.500
BLOCK 15	-20.713	-19.136	7.927	-0.797	-0.305	-0.736	18.005	-0.739	70.000	21.123	20.145	-6.352	0.879	0.264	0.839	-81.425	67.500	72.500
BLOCK 16	-21.123	-20.145	6.352	-0.879	-0.264	-0.839	18.971	-0.589	75.000	21.515	21.005	-4.657	0.877	0.190	0.857	-90.605	72.500	77.500
BLOCK 17	-21.515	-21.005	4.657	-0.877	-0.190	-0.857	19.956	-0.416	80.000	21.878	21.690	-2.856	0.953	0.124	0.944	-100.352	77.500	82.500
BLOCK 18	-21.878	-21.690	2.856	-0.953	-0.124	-0.944	20.952	-0.219	85.000	22.201	22.180	-0.968	0.944	0.041	0.943	-110.658	82.500	87.500
BLOCK 19	-22.201	-22.180	0.968	-0.944	-0.041	-0.943	21.952	0.000	90.000	22.450	22.450	0.000	0.026	0.000	0.026	-116.474	87.500	90.000
BLOCK 20	-22.450	-22.450	0.000	-0.026	0.000	-0.026	22.952	0.000	90.000	22.720	22.720	0.000	-0.026	0.000	-0.026	-116.474	90.000	90.000
BLOCK 21	-22.720	-22.720	0.000	0.026	0.000	0.026	23.952	0.000	90.000	22.990	22.990	0.000	0.026	0.000	0.026	-116.474	90.000	90.000
BLOCK 22	-22.990	-22.990	0.000	-0.026	0.000	-0.026	24.952	0.000	90.000	23.260	23.260	0.000	-0.026	0.000	-0.026	-116.474	90.000	90.000
BLOCK 23	-23.260	-23.260	0.000	0.026	0.000	0.026	25.952	0.000	90.000	23.530	23.530	0.000	0.026	0.000	0.026	-116.474	90.000	90.000
BLOCK 24	-23.530	-23.530	0.000	-0.026	0.000	-0.026	26.952	0.000	90.000	23.800	23.800	0.000	-0.026	0.000	-0.026	-116.474	90.000	90.000
BLOCK 25	-23.800	-23.800	0.000	0.026	0.000	0.026	27.952	0.000	90.000	24.070	24.070	0.000	0.026	0.000	0.026	-116.474	90.000	90.000
BLOCK 26	-24.070	-24.070	0.000	-0.026	0.000	-0.026	28.952	0.000	90.000	24.340	24.340	0.000	-0.026	0.000	-0.026	-116.474	90.000	90.000
BLOCK 27	-24.340	-24.340	0.000	0.026	0.000	0.026	29.952	0.000	90.000	24.610	24.610	0.000	0.026	0.000	0.026	-116.474	90.000	90.000
BLOCK 28	-24.610	-24.610	0.000	-0.026	0.000	-0.026	30.952	0.000	90.000	24.880	24.880	0.000	-0.026	0.000	-0.026	-116.474	90.000	90.000

-17.455
24.880

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

AM AN	AO AP R(1)	AQ AR R(1V)	AS AT R(1H)	AU AV FRIC(1)	AW AX FRIC(1V)	AY AZ FRIC(1H)	BA BB Load(H)	BC BD R(2)	BE BF R(2V)	BG BH R(2H)	BI BJ FRIC(2)	BK BL FRIC(2V)	BM BN FRIC(2H)	BO BP M(cgH)	BQ BR SIN ALPHA 1	BS BT COS ALPHA 1	BU BV SIN ALPHA 2	BW BX COS ALPHA 2
BLOCK 1	-5.620	0.000	5.620	0.000	0.000	0.000	0.000	5.615	0.245	-5.609	-0.245	-0.245	-0.011	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-5.615	-0.245	5.609	0.245	0.245	0.011	-0.026	5.610	0.732	-5.562	-0.244	-0.242	-0.032	-2.998	0.044	0.999	0.131	0.991
BLOCK 3	-5.610	-0.732	5.562	0.244	0.242	0.032	-0.053	5.620	1.216	-5.487	-0.248	-0.242	-0.054	-6.292	0.131	0.991	0.216	0.976
BLOCK 4	-5.620	-1.216	5.487	0.248	0.242	0.054	-0.082	5.644	1.697	-5.383	-0.251	-0.239	-0.075	-9.902	0.216	0.976	0.301	0.954
BLOCK 5	-5.644	-1.697	5.383	0.251	0.239	0.075	-0.111	5.681	2.174	-5.249	-0.257	-0.238	-0.098	-13.840	0.301	0.954	0.383	0.924
BLOCK 6	-5.681	-2.174	5.249	0.257	0.238	0.098	-0.143	5.730	2.646	-5.082	-0.264	-0.234	-0.122	-18.118	0.383	0.924	0.462	0.887
BLOCK 7	-5.730	-2.646	5.082	0.264	0.234	0.122	-0.177	5.787	3.109	-4.881	-0.272	-0.230	-0.146	-22.731	0.462	0.887	0.537	0.843
BLOCK 8	-5.787	-3.109	4.881	0.272	0.230	0.146	-0.213	5.852	3.563	-4.643	-0.282	-0.224	-0.172	-27.669	0.537	0.843	0.609	0.793
BLOCK 9	-5.852	-3.563	4.643	0.282	0.224	0.172	-0.251	5.923	4.001	-4.367	-0.292	-0.215	-0.197	-32.905	0.609	0.793	0.676	0.737
BLOCK 10	-5.923	-4.001	4.367	0.292	0.215	0.197	-0.291	5.996	4.420	-4.051	-0.302	-0.204	-0.223	-38.397	0.676	0.737	0.737	0.676
BLOCK 11	-5.996	-4.420	4.051	0.302	0.204	0.223	-0.333	6.068	4.814	-3.694	-0.311	-0.189	-0.247	-44.084	0.737	0.676	0.793	0.609
BLOCK 12	-6.068	-4.814	3.694	0.311	0.189	0.247	-0.376	6.135	5.174	-3.296	-0.318	-0.171	-0.268	-49.881	0.793	0.609	0.843	0.537
BLOCK 13	-6.135	-5.174	3.296	0.318	0.171	0.268	-0.420	6.193	5.493	-2.860	-0.321	-0.148	-0.285	-55.675	0.843	0.537	0.887	0.462
BLOCK 14	-6.193	-5.493	2.860	0.321	0.148	0.285	-0.464	6.238	5.763	-2.387	-0.318	-0.122	-0.294	-61.319	0.887	0.462	0.924	0.383
BLOCK 15	-6.238	-5.763	2.387	0.318	0.122	0.294	-0.508	6.266	5.976	-1.884	-0.303	-0.091	-0.289	-66.620	0.924	0.383	0.954	0.301
BLOCK 16	-6.266	-5.976	1.884	0.303	0.091	0.289	-0.550	6.275	6.126	-1.358	-0.272	-0.059	-0.265	-71.331	0.954	0.301	0.976	0.216
BLOCK 17	-6.275	-6.126	1.358	0.272	0.059	0.265	-0.590	6.267	6.213	-0.818	-0.218	-0.028	-0.216	-75.143	0.976	0.216	0.991	0.131
BLOCK 18	-6.267	-6.213	0.818	0.218	0.028	0.216	-0.626	6.254	6.248	-0.273	-0.135	-0.006	-0.135	-77.685	0.991	0.131	0.999	0.044
BLOCK 19	-6.254	-6.248	0.273	0.135	0.006	0.135	-0.659	6.254	6.254	0.000	0.251	0.000	0.251	-76.991	0.999	0.044	1.000	0.000
BLOCK 20	-6.254	-6.254	0.000	-0.251	0.000	-0.251	-0.689	6.254	6.254	0.000	0.939	0.000	0.939	-69.850	1.000	0.000	1.000	0.000
BLOCK 21	-6.254	-6.254	0.000	-0.939	0.000	-0.939	-0.719	6.254	6.254	0.000	1.658	0.000	1.658	-54.267	1.000	0.000	1.000	0.000
BLOCK 22	-6.254	-6.254	0.000	-1.658	0.000	-1.658	-0.749	6.254	6.254	0.000	2.406	0.000	2.406	-29.881	1.000	0.000	1.000	0.000
BLOCK 23	-6.254	-6.254	0.000	-2.406	0.000	-2.406	-0.779	6.254	6.254	0.000	3.185	0.000	3.185	3.668	1.000	0.000	1.000	0.000
BLOCK 24	-6.254	-6.254	0.000	-3.185	0.000	-3.185	-0.809	6.254	6.254	0.000	3.994	0.000	3.994	46.739	1.000	0.000	1.000	0.000
BLOCK 25	-6.254	-6.254	0.000	-3.994	0.000	-3.994	-0.839	6.254	6.254	0.000	4.832	0.000	4.832	99.694	1.000	0.000	1.000	0.000
BLOCK 26	-6.254	-6.254	0.000	-4.832	0.000	-4.832	-0.869	6.254	6.254	0.000	5.701	0.000	5.701	162.890	1.000	0.000	1.000	0.000
BLOCK 27	-6.254	-6.254	0.000	-5.701	0.000	-5.701	-0.899	6.254	6.254	0.000	6.599	0.000	6.599	236.690	1.000	0.000	1.000	0.000
BLOCK 28	-6.254	-6.254	0.000	-6.599	0.000	-6.599	-0.929	6.254	6.254	0.000	7.528	0.000	7.528	321.452	1.000	0.000	1.000	0.000
							-13.148											

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

FILL 10 FEET ABOVE ARCH

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-22.470	0.000	0.000	0.000	22.465	0.000	0.123			0.000	0.000	
BLOCK 2	-22.465	0.000	-0.123	-6.003	22.548	-0.266	-0.052			-6.003	-0.266	
BLOCK 3	-22.548	-0.266	0.052	-12.922	22.684	-0.571	0.251			-6.919	-0.305	
BLOCK 4	-22.684	-0.571	-0.251	-21.095	22.880	-0.928	0.130			-8.173	-0.357	
BLOCK 5	-22.880	-0.928	-0.130	-29.659	23.130	-1.299	0.271			-8.564	-0.370	
BLOCK 6	-23.130	-1.299	-0.271	-38.937	23.434	-1.695	0.202			-9.278	-0.396	
BLOCK 7	-23.434	-1.695	-0.202	-48.731	23.784	-2.106	0.305			-9.794	-0.412	
BLOCK 8	-23.784	-2.106	-0.305	-59.197	24.175	-2.539	0.262			-10.467	-0.433	
BLOCK 9	-24.175	-2.539	-0.262	-70.248	24.602	-2.989	0.350			-11.050	-0.449	
BLOCK 10	-24.602	-2.989	-0.350	-81.952	25.056	-3.456	0.324			-11.704	-0.467	
BLOCK 11	-25.056	-3.456	-0.324	-94.235	25.528	-3.937	0.406			-12.283	-0.481	
BLOCK 12	-25.528	-3.937	-0.406	-107.095	26.009	-4.431	0.393			-12.860	-0.494	
BLOCK 13	-26.009	-4.431	-0.393	-120.424	26.487	-4.935	0.477			-13.330	-0.503	
BLOCK 14	-26.487	-4.935	-0.477	-134.136	26.951	-5.443	0.479			-13.711	-0.509	
BLOCK 15	-26.951	-5.443	-0.479	-148.044	27.389	-5.951	0.576			-13.909	-0.508	
BLOCK 16	-27.389	-5.951	-0.576	-161.936	27.789	-6.451	0.606			-13.892	-0.500	
BLOCK 17	-27.789	-6.451	-0.606	-175.495	28.145	-6.933	0.735			-13.559	-0.482	
BLOCK 18	-28.145	-6.933	-0.735	-188.343	28.454	-7.384	0.809			-12.848	-0.452	
BLOCK 19	-28.454	-7.384	-0.809	-193.465	28.703	-7.563	0.276			-5.122	-0.178	
BLOCK 20	-28.703	-7.563	-0.276	-186.324	28.973	-7.316	0.914	0.032	1.807	7.141	0.246	0.378
BLOCK 21	-28.973	-7.316	-0.914	-170.741	29.243	-6.783	1.683	0.058	3.295	15.583	0.533	1.067
BLOCK 22	-29.243	-6.783	-1.683	-146.355	29.513	-5.957	2.381	0.081	4.612	24.386	0.826	2.028
BLOCK 23	-29.513	-5.957	-2.381	-112.806	29.783	-4.831	3.211	0.108	6.153	33.549	1.126	3.307
BLOCK 24	-29.783	-4.831	-3.211	-69.734	30.053	-3.397	3.968	0.132	7.521	43.071	1.433	4.864
BLOCK 25	-30.053	-3.397	-3.968	-16.780	30.323	-1.651	4.858	0.160	9.101	52.954	1.746	6.739
BLOCK 26	-30.323	-1.651	-4.858	46.417	30.593	0.415	5.675	0.186	10.509	63.197	2.066	8.891
BLOCK 27	-30.593	0.415	-5.675	120.216	30.863	2.806	6.625	0.215	12.115	73.799	2.391	11.353
BLOCK 28	-30.863	2.806	-6.625	204.978	31.133	5.528	7.502	0.241	13.548	84.762	2.723	14.086

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH15-DISC1
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=15.0 FEET
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL 15 FEET ABOVE ARCH

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-23.728	0.000	23.728	0.000	0.000	0.000	15.000	-0.900	0.000	23.728	1.035	-23.705	0.518	0.517	0.023	0.000	0.000	2.500
BLOCK 2	-23.728	-1.035	23.705	-0.518	-0.517	-0.023	15.087	-1.804	5.000	23.816	3.109	-23.612	0.543	0.538	0.071	-5.730	2.500	7.500
BLOCK 3	-23.816	-3.109	23.612	-0.543	-0.538	-0.071	15.261	-1.803	10.000	23.942	5.182	-23.375	0.769	0.750	0.166	-12.697	7.500	12.500
BLOCK 4	-23.942	-5.182	23.375	-0.769	-0.750	-0.166	15.520	-1.799	15.000	24.113	7.251	-22.997	0.703	0.670	0.211	-20.397	12.500	17.500
BLOCK 5	-24.113	-7.251	22.997	-0.703	-0.670	-0.211	15.862	-1.789	20.000	24.327	9.310	-22.475	0.811	0.750	0.311	-28.188	17.500	22.500
BLOCK 6	-24.327	-9.310	22.475	-0.811	-0.750	-0.311	16.284	-1.771	25.000	24.582	11.351	-21.804	0.781	0.692	0.360	-36.276	22.500	27.500
BLOCK 7	-24.582	-11.351	21.804	-0.781	-0.692	-0.360	16.784	-1.744	30.000	24.874	13.365	-20.979	0.866	0.730	0.465	-44.541	27.500	32.500
BLOCK 8	-24.874	-13.365	20.979	-0.866	-0.730	-0.465	17.358	-1.706	35.000	25.201	15.341	-19.993	0.855	0.678	0.521	-53.113	32.500	37.500
BLOCK 9	-25.201	-15.341	19.993	-0.855	-0.678	-0.521	18.001	-1.655	40.000	25.557	17.266	-18.842	0.933	0.688	0.630	-61.971	37.500	42.500
BLOCK 10	-25.557	-17.266	18.842	-0.933	-0.688	-0.630	18.708	-1.587	45.000	25.938	19.123	-17.523	0.935	0.631	0.689	-71.211	42.500	47.500
BLOCK 11	-25.938	-19.123	17.523	-0.935	-0.631	-0.689	19.474	-1.502	50.000	26.338	20.895	-16.034	1.009	0.614	0.801	-80.849	47.500	52.500
BLOCK 12	-26.338	-20.895	16.034	-1.009	-0.614	-0.801	20.293	-1.397	55.000	26.752	22.562	-14.374	1.019	0.547	0.859	-90.960	52.500	57.500
BLOCK 13	-26.752	-22.562	14.374	-1.019	-0.547	-0.859	21.159	-1.270	60.000	27.172	24.102	-12.546	1.091	0.504	0.968	-101.571	57.500	62.500
BLOCK 14	-27.172	-24.102	12.546	-1.091	-0.504	-0.968	22.065	-1.119	65.000	27.591	25.491	-10.559	1.104	0.423	1.020	-112.740	62.500	67.500
BLOCK 15	-27.591	-25.491	10.559	-1.104	-0.423	-1.020	23.005	-0.944	70.000	28.001	26.705	-8.420	1.173	0.353	1.118	-124.490	67.500	72.500
BLOCK 16	-28.001	-26.705	8.420	-1.173	-0.353	-1.118	23.971	-0.744	75.000	28.392	27.719	-6.145	1.184	0.256	1.156	-136.853	72.500	77.500
BLOCK 17	-28.392	-27.719	6.145	-1.184	-0.256	-1.156	24.956	-0.520	80.000	28.755	28.509	-3.753	1.246	0.163	1.236	-149.831	77.500	82.500
BLOCK 18	-28.755	-28.509	3.753	-1.246	-0.163	-1.236	25.952	-0.271	85.000	29.078	29.051	-1.268	1.251	0.055	1.249	-163.417	82.500	87.500
BLOCK 19	-29.078	-29.051	1.268	-1.251	-0.055	-1.249	26.952	0.000	90.000	29.321	29.321	0.000	0.019	0.000	0.019	-171.035	87.500	90.000
BLOCK 20	-29.321	-29.321	0.000	-0.019	0.000	-0.019	27.952	0.000	90.000	29.591	29.591	0.000	-0.019	0.000	-0.019	-171.035	90.000	90.000
BLOCK 21	-29.591	-29.591	0.000	0.019	0.000	0.019	28.952	0.000	90.000	29.861	29.861	0.000	0.019	0.000	0.019	-171.035	90.000	90.000
BLOCK 22	-29.861	-29.861	0.000	-0.019	0.000	-0.019	29.952	0.000	90.000	30.131	30.131	0.000	-0.019	0.000	-0.019	-171.035	90.000	90.000
BLOCK 23	-30.131	-30.131	0.000	0.019	0.000	0.019	30.952	0.000	90.000	30.401	30.401	0.000	0.019	0.000	0.019	-171.035	90.000	90.000
BLOCK 24	-30.401	-30.401	0.000	-0.019	0.000	-0.019	31.952	0.000	90.000	30.671	30.671	0.000	-0.019	0.000	-0.019	-171.035	90.000	90.000
BLOCK 25	-30.671	-30.671	0.000	0.019	0.000	0.019	32.952	0.000	90.000	30.941	30.941	0.000	0.019	0.000	0.019	-171.035	90.000	90.000
BLOCK 26	-30.941	-30.941	0.000	-0.019	0.000	-0.019	33.952	0.000	90.000	31.211	31.211	0.000	-0.019	0.000	-0.019	-171.035	90.000	90.000
BLOCK 27	-31.211	-31.211	0.000	0.019	0.000	0.019	34.952	0.000	90.000	31.481	31.481	0.000	0.019	0.000	0.019	-171.035	90.000	90.000
BLOCK 28	-31.481	-31.481	0.000	-0.019	0.000	-0.019	35.952	0.000	90.000	31.751	31.751	0.000	-0.019	0.000	-0.019	-171.035	90.000	90.000

-24.326
31.751

AM AN	AO AP	AQ AR	AS AT	AU AV	AW AX	AY AZ	BA BB	BC BD	BE BF	BG BH	BI BJ	BK BL	BM BN	BO BP	BQ BR	BS BT	BU BV	BW BX
	R(1)	R(1V)	R(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	Load(H)	R(2)	R(2V)	R(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgH)	SIN ALPHA 1	COS ALPHA 1	SIN ALPHA 2	COS ALPHA 2
BLOCK 1	-7.230	0.000	7.230	0.000	0.000	0.000	0.000	7.223	0.315	-7.216	-0.315	-0.315	-0.014	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-7.223	-0.315	7.216	0.315	0.315	0.014	-0.039	7.211	0.941	-7.150	-0.314	-0.311	-0.041	-3.912	0.044	0.999	0.131	0.991
BLOCK 3	-7.211	-0.941	7.150	0.314	0.311	0.041	-0.080	7.214	1.561	-7.043	-0.316	-0.309	-0.068	-8.247	0.131	0.991	0.216	0.976
BLOCK 4	-7.214	-1.561	7.043	0.316	0.309	0.068	-0.121	7.229	2.174	-6.895	-0.318	-0.304	-0.096	-13.014	0.216	0.976	0.301	0.954
BLOCK 5	-7.229	-2.174	6.895	0.318	0.304	0.096	-0.163	7.256	2.777	-6.704	-0.324	-0.299	-0.124	-18.214	0.301	0.954	0.383	0.924
BLOCK 6	-7.256	-2.777	6.704	0.324	0.299	0.124	-0.206	7.294	3.368	-6.469	-0.329	-0.292	-0.152	-23.837	0.383	0.924	0.462	0.887
BLOCK 7	-7.294	-3.368	6.469	0.329	0.292	0.152	-0.252	7.338	3.943	-6.189	-0.336	-0.283	-0.181	-29.858	0.462	0.887	0.537	0.843
BLOCK 8	-7.338	-3.943	6.189	0.336	0.283	0.181	-0.299	7.389	4.498	-5.862	-0.343	-0.272	-0.209	-36.241	0.537	0.843	0.609	0.793
BLOCK 9	-7.389	-4.498	5.862	0.343	0.272	0.209	-0.347	7.443	5.028	-5.487	-0.350	-0.258	-0.236	-42.928	0.609	0.793	0.676	0.737
BLOCK 10	-7.443	-5.028	5.487	0.350	0.258	0.236	-0.397	7.496	5.527	-5.064	-0.356	-0.241	-0.263	-49.847	0.676	0.737	0.737	0.676
BLOCK 11	-7.496	-5.527	5.064	0.356	0.241	0.263	-0.448	7.546	5.987	-4.594	-0.360	-0.219	-0.286	-56.897	0.737	0.676	0.793	0.609
BLOCK 12	-7.546	-5.987	4.594	0.360	0.219	0.286	-0.499	7.588	6.399	-4.077	-0.360	-0.194	-0.304	-63.953	0.793	0.609	0.843	0.537
BLOCK 13	-7.588	-6.399	4.077	0.360	0.194	0.304	-0.550	7.617	6.756	-3.517	-0.354	-0.163	-0.314	-70.854	0.843	0.537	0.887	0.462
BLOCK 14	-7.617	-6.756	3.517	0.354	0.163	0.314	-0.600	7.629	7.049	-2.920	-0.337	-0.129	-0.311	-77.399	0.887	0.462	0.924	0.383
BLOCK 15	-7.629	-7.049	2.920	0.337	0.129	0.311	-0.649	7.622	7.269	-2.292	-0.305	-0.092	-0.291	-83.331	0.924	0.383	0.954	0.301
BLOCK 16	-7.622	-7.269	2.292	0.305	0.092	0.291	-0.695	7.595	7.415	-1.644	-0.250	-0.054	-0.244	-88.331	0.954	0.301	0.976	0.216
BLOCK 17	-7.595	-7.415	1.644	0.250	0.054	0.244	-0.737	7.555	7.491	-0.986	-0.166	-0.022	-0.164	-92.007	0.976	0.216	0.991	0.131
BLOCK 18	-7.555	-7.491	0.986	0.166	0.022	0.164	-0.776	7.522	7.514	-0.328	-0.047	-0.002	-0.047	-93.911	0.991	0.131	0.999	0.044
BLOCK 19	-7.522	-7.514	0.328	0.047	0.002	0.047	-0.809	7.516	7.516	0.000	0.434	0.000	0.434	-91.591	0.999	0.044	1.000	0.000
BLOCK 20	-7.516	-7.516	0.000	-0.434	0.000	-0.434	-0.839	7.516	7.516	0.000	1.272	0.000	1.272	-81.357	1.000	0.000	1.000	0.000
BLOCK 21	-7.516	-7.516	0.000	-1.272	0.000	-1.272	-0.869	7.516	7.516	0.000	2.141	0.000	2.141	-60.880	1.000	0.000	1.000	0.000
BLOCK 22	-7.516	-7.516	0.000	-2.141	0.000	-2.141	-0.899	7.516	7.516	0.000	3.039	0.000	3.039	-29.801	1.000	0.000	1.000	0.000
BLOCK 23	-7.516	-7.516	0.000	-3.039	0.000	-3.039	-0.929	7.516	7.516	0.000	3.968	0.000	3.968	12.262	1.000	0.000	1.000	0.000
BLOCK 24	-7.516	-7.516	0.000	-3.968	0.000	-3.968	-0.959	7.516	7.516	0.000	4.926	0.000	4.926	65.606	1.000	0.000	1.000	0.000
BLOCK 25	-7.516	-7.516	0.000	-4.926	0.000	-4.926	-0.989	7.516	7.516	0.000	5.915	0.000	5.915	130.654	1.000	0.000	1.000	0.000
BLOCK 26	-7.516	-7.516	0.000	-5.915	0.000	-5.915	-1.019	7.516	7.516	0.000	6.933	0.000	6.933	207.744	1.000	0.000	1.000	0.000
BLOCK 27	-7.516	-7.516	0.000	-6.933	0.000	-6.933	-1.049	7.516	7.516	0.000	7.982	0.000	7.982	297.237	1.000	0.000	1.000	0.000
BLOCK 28	-7.516	-7.516	0.000	-7.982	0.000	-7.982	-1.079	7.516	7.516	0.000	9.061	0.000	9.061	399.493	1.000	0.000	1.000	0.000

-16.291

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

FILL 15 FEET ABOVE ARCH

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-30.958	0.000	0.000	0.000	30.951	0.000	0.202			0.000	0.000	
BLOCK 2	-30.951	0.000	-0.202	-9.642	31.027	-0.311	0.229			-9.642	-0.311	
BLOCK 3	-31.027	-0.311	-0.229	-20.944	31.156	-0.674	0.452			-11.301	-0.363	
BLOCK 4	-31.156	-0.674	-0.452	-33.411	31.342	-1.071	0.384			-12.468	-0.398	
BLOCK 5	-31.342	-1.071	-0.384	-46.402	31.583	-1.483	0.488			-12.991	-0.411	
BLOCK 6	-31.583	-1.483	-0.488	-60.113	31.875	-1.913	0.452			-13.711	-0.430	
BLOCK 7	-31.875	-1.913	-0.452	-74.399	32.212	-2.356	0.530			-14.286	-0.444	
BLOCK 8	-32.212	-2.356	-0.530	-89.354	32.590	-2.815	0.512			-14.955	-0.459	
BLOCK 9	-32.590	-2.815	-0.512	-104.899	32.999	-3.286	0.583			-15.546	-0.471	
BLOCK 10	-32.999	-3.286	-0.583	-121.058	33.434	-3.770	0.579			-16.159	-0.483	
BLOCK 11	-33.434	-3.770	-0.579	-137.746	33.884	-4.262	0.649			-16.687	-0.492	
BLOCK 12	-33.884	-4.262	-0.649	-154.913	34.339	-4.762	0.659			-17.167	-0.500	
BLOCK 13	-34.339	-4.762	-0.659	-172.425	34.789	-5.265	0.737			-17.512	-0.503	
BLOCK 14	-34.789	-5.265	-0.737	-190.139	35.220	-5.768	0.767			-17.714	-0.503	
BLOCK 15	-35.220	-5.768	-0.767	-207.821	35.623	-6.265	0.868			-17.682	-0.496	
BLOCK 16	-35.623	-6.265	-0.868	-225.184	35.987	-6.747	0.934			-17.363	-0.482	
BLOCK 17	-35.987	-6.747	-0.934	-241.838	36.311	-7.206	1.080			-16.654	-0.459	
BLOCK 18	-36.311	-7.206	-1.080	-257.328	36.600	-7.629	1.204			-15.490	-0.423	
BLOCK 19	-36.600	-7.629	-1.204	-262.626	36.837	-7.773	0.453			-5.298	-0.144	
BLOCK 20	-36.837	-7.773	-0.453	-252.392	37.107	-7.497	1.253	0.034	1.934	10.234	0.276	0.405
BLOCK 21	-37.107	-7.497	-1.253	-231.915	37.377	-6.949	2.160	0.058	3.307	20.477	0.548	1.096
BLOCK 22	-37.377	-6.949	-2.160	-200.835	37.647	-6.124	3.020	0.080	4.587	31.079	0.826	2.052
BLOCK 23	-37.647	-6.124	-3.020	-158.793	37.917	-5.015	3.987	0.105	6.002	42.042	1.109	3.300
BLOCK 24	-37.917	-5.015	-3.987	-105.429	38.187	-3.617	4.907	0.129	7.323	53.365	1.397	4.817
BLOCK 25	-38.187	-3.617	-4.907	-40.381	38.457	-1.926	5.934	0.154	8.771	65.048	1.691	6.626
BLOCK 26	-38.457	-1.926	-5.934	36.709	38.727	0.065	6.914	0.179	10.123	77.090	1.991	8.702
BLOCK 27	-38.727	0.065	-6.914	126.202	38.997	2.359	8.001	0.205	11.594	89.493	2.295	11.065
BLOCK 28	-38.997	2.359	-8.001	228.458	39.267	4.964	9.042	0.230	12.967	102.256	2.604	13.689

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH20-DISC2
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=20.0 FEET
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL 20 FEET ABOVE ARCH
PAGE 29 OF
7-1

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-30.606	0.000	30.606	0.000	0.000	0.000	20.000	-1.200	0.000	30.606	1.335	-30.577	0.668	0.667	0.029	0.000	0.000	2.500
BLOCK 2	-30.606	-1.335	30.577	-0.668	-0.667	-0.029	20.087	-2.401	5.000	30.693	4.006	-30.431	0.894	0.886	0.117	-8.456	2.500	7.500
BLOCK 3	-30.693	-4.006	30.431	-0.894	-0.886	-0.117	20.261	-2.394	10.000	30.820	6.671	-30.089	1.039	1.014	0.225	-18.764	7.500	12.500
BLOCK 4	-30.820	-6.671	30.089	-1.039	-1.014	-0.225	20.520	-2.378	15.000	30.991	9.319	-29.556	1.025	0.977	0.308	-29.600	12.500	17.500
BLOCK 5	-30.991	-9.319	29.556	-1.025	-0.977	-0.308	20.862	-2.352	20.000	31.205	11.942	-28.829	1.095	1.011	0.419	-40.557	17.500	22.500
BLOCK 6	-31.205	-11.942	28.829	-1.095	-1.011	-0.419	21.284	-2.315	25.000	31.459	14.526	-27.905	1.095	0.971	0.506	-51.732	22.500	27.500
BLOCK 7	-31.459	-14.526	27.905	-1.095	-0.971	-0.506	21.784	-2.264	30.000	31.752	17.060	-26.779	1.154	0.973	0.620	-63.082	27.500	32.500
BLOCK 8	-31.752	-17.060	26.779	-1.154	-0.973	-0.620	22.358	-2.198	35.000	32.078	19.528	-25.449	1.166	0.925	0.710	-74.697	32.500	37.500
BLOCK 9	-32.078	-19.528	25.449	-1.166	-0.925	-0.710	23.001	-2.114	40.000	32.434	21.912	-23.913	1.223	0.902	0.826	-86.599	37.500	42.500
BLOCK 10	-32.434	-21.912	23.913	-1.223	-0.902	-0.826	23.708	-2.012	45.000	32.815	24.194	-22.170	1.244	0.840	0.917	-98.868	42.500	47.500
BLOCK 11	-32.815	-24.194	22.170	-1.244	-0.840	-0.917	24.474	-1.888	50.000	33.216	26.352	-20.220	1.301	0.792	1.032	-111.546	47.500	52.500
BLOCK 12	-33.216	-26.352	20.220	-1.301	-0.792	-1.032	25.293	-1.741	55.000	33.629	28.363	-18.069	1.327	0.713	1.119	-124.706	52.500	57.500
BLOCK 13	-33.629	-28.363	18.069	-1.327	-0.713	-1.119	26.159	-1.570	60.000	34.049	30.202	-15.722	1.384	0.639	1.228	-138.393	57.500	62.500
BLOCK 14	-34.049	-30.202	15.722	-1.384	-0.639	-1.228	27.065	-1.373	65.000	34.469	31.845	-13.191	1.412	0.540	1.304	-152.664	62.500	67.500
BLOCK 15	-34.469	-31.845	13.191	-1.412	-0.540	-1.304	28.005	-1.149	70.000	34.878	33.264	-10.488	1.466	0.441	1.398	-167.555	67.500	72.500
BLOCK 16	-34.878	-33.264	10.488	-1.466	-0.441	-1.398	28.971	-0.900	75.000	35.270	34.434	-7.634	1.491	0.323	1.456	-183.100	72.500	77.500
BLOCK 17	-35.270	-34.434	7.634	-1.491	-0.323	-1.456	29.956	-0.624	80.000	35.633	35.328	-4.651	1.540	0.201	1.527	-199.309	77.500	82.500
BLOCK 18	-35.633	-35.328	4.651	-1.540	-0.201	-1.527	30.952	-0.324	85.000	35.956	35.922	-1.568	1.557	0.068	1.556	-216.177	82.500	87.500
BLOCK 19	-35.956	-35.922	1.568	-1.557	-0.068	-1.556	31.952	0.000	90.000	36.192	36.192	0.000	0.012	0.000	0.012	-225.596	87.500	90.000
BLOCK 20	-36.192	-36.192	0.000	-0.012	0.000	-0.012	32.952	0.000	90.000	36.462	36.462	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 21	-36.462	-36.462	0.000	0.012	0.000	0.012	33.952	0.000	90.000	36.732	36.732	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 22	-36.732	-36.732	0.000	-0.012	0.000	-0.012	34.952	0.000	90.000	37.002	37.002	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 23	-37.002	-37.002	0.000	0.012	0.000	0.012	35.952	0.000	90.000	37.272	37.272	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 24	-37.272	-37.272	0.000	-0.012	0.000	-0.012	36.952	0.000	90.000	37.542	37.542	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 25	-37.542	-37.542	0.000	0.012	0.000	0.012	37.952	0.000	90.000	37.812	37.812	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 26	-37.812	-37.812	0.000	-0.012	0.000	-0.012	38.952	0.000	90.000	38.082	38.082	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 27	-38.082	-38.082	0.000	0.012	0.000	0.012	39.952	0.000	90.000	38.352	38.352	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 28	-38.352	-38.352	0.000	-0.012	0.000	-0.012	40.952	0.000	90.000	38.622	38.622	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000

-31.197
38.622

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

FILL 20 FEET ABOVE ARCH

AM AN	AO AP R(1)	AQ AR R(1V)	AS AT R(1H)	AU AV FRIC(1)	AW AX FRIC(1V)	AY AZ FRIC(1H)	BA BB Load(H)	BC BD R(2)	BE BF R(2V)	BG BH R(2H)	BI BJ FRIC(2)	BK BL FRIC(2V)	BM BN FRIC(2H)	BO BP M(cgH)	BQ BR SIN ALPHA 1	BS BT COS ALPHA 1	BU BV SIN ALPHA 2	BW BX COS ALPHA 2
BLOCK 1	-8.935	0.000	8.935	0.000	0.000	0.000	0.000	8.926	0.389	-8.918	-0.390	-0.389	-0.017	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-8.926	-0.389	8.918	0.390	0.389	0.017	-0.053	8.908	1.163	-8.832	-0.387	-0.384	-0.051	-4.872	0.044	0.999	0.131	0.991
BLOCK 3	-8.908	-1.163	8.832	0.387	0.384	0.051	-0.106	8.904	1.927	-8.693	-0.390	-0.380	-0.084	-10.295	0.131	0.991	0.216	0.976
BLOCK 4	-8.904	-1.927	8.693	0.390	0.380	0.084	-0.159	8.913	2.680	-8.500	-0.391	-0.373	-0.117	-16.271	0.216	0.976	0.301	0.954
BLOCK 5	-8.913	-2.680	8.500	0.391	0.373	0.117	-0.214	8.932	3.418	-8.252	-0.396	-0.365	-0.151	-22.785	0.301	0.954	0.383	0.924
BLOCK 6	-8.932	-3.418	8.252	0.396	0.365	0.151	-0.270	8.962	4.138	-7.949	-0.400	-0.354	-0.185	-29.813	0.383	0.924	0.462	0.887
BLOCK 7	-8.962	-4.138	7.949	0.400	0.354	0.185	-0.327	8.998	4.835	-7.589	-0.406	-0.342	-0.218	-37.307	0.462	0.887	0.537	0.843
BLOCK 8	-8.998	-4.835	7.589	0.406	0.342	0.218	-0.385	9.040	5.503	-7.172	-0.411	-0.326	-0.250	-45.210	0.537	0.843	0.609	0.793
BLOCK 9	-9.040	-5.503	7.172	0.411	0.326	0.250	-0.444	9.084	6.137	-6.697	-0.417	-0.307	-0.282	-53.438	0.609	0.793	0.676	0.737
BLOCK 10	-9.084	-6.137	6.697	0.417	0.307	0.282	-0.503	9.126	6.728	-6.165	-0.421	-0.284	-0.310	-61.889	0.676	0.737	0.737	0.676
BLOCK 11	-9.126	-6.728	6.165	0.421	0.284	0.310	-0.562	9.163	7.270	-5.578	-0.422	-0.257	-0.335	-70.433	0.737	0.676	0.793	0.609
BLOCK 12	-9.163	-7.270	5.578	0.422	0.257	0.335	-0.622	9.191	7.752	-4.939	-0.419	-0.225	-0.353	-78.913	0.793	0.609	0.843	0.537
BLOCK 13	-9.191	-7.752	4.939	0.419	0.225	0.353	-0.680	9.205	8.165	-4.251	-0.408	-0.188	-0.362	-87.132	0.843	0.537	0.887	0.462
BLOCK 14	-9.205	-8.165	4.251	0.408	0.188	0.362	-0.736	9.201	8.501	-3.521	-0.384	-0.147	-0.355	-94.853	0.887	0.462	0.924	0.383
BLOCK 15	-9.201	-8.501	3.521	0.384	0.147	0.355	-0.789	9.176	8.751	-2.759	-0.343	-0.103	-0.328	-101.780	0.924	0.383	0.954	0.301
BLOCK 16	-9.176	-8.751	2.759	0.343	0.103	0.328	-0.840	9.131	8.914	-1.976	-0.278	-0.060	-0.271	-107.549	0.954	0.301	0.976	0.216
BLOCK 17	-9.131	-8.914	1.976	0.278	0.060	0.271	-0.885	9.075	8.998	-1.185	-0.179	-0.023	-0.178	-111.727	0.976	0.216	0.991	0.131
BLOCK 18	-9.075	-8.998	1.185	0.179	0.023	0.178	-0.925	9.032	9.023	-0.394	-0.043	-0.002	-0.043	-113.824	0.991	0.131	0.999	0.044
BLOCK 19	-9.032	-9.023	0.394	0.043	0.002	0.043	-0.959	9.025	9.025	0.000	0.521	0.000	0.521	-110.956	0.999	0.044	1.000	0.000
BLOCK 20	-9.025	-9.025	0.000	-0.521	0.000	-0.521	-0.989	9.025	9.025	0.000	1.510	0.000	1.510	-98.768	1.000	0.000	1.000	0.000
BLOCK 21	-9.025	-9.025	0.000	-1.510	0.000	-1.510	-1.019	9.025	9.025	0.000	2.528	0.000	2.528	-74.538	1.000	0.000	1.000	0.000
BLOCK 22	-9.025	-9.025	0.000	-2.528	0.000	-2.528	-1.049	9.025	9.025	0.000	3.577	0.000	3.577	-37.905	1.000	0.000	1.000	0.000
BLOCK 23	-9.025	-9.025	0.000	-3.577	0.000	-3.577	-1.079	9.025	9.025	0.000	4.656	0.000	4.656	11.490	1.000	0.000	1.000	0.000
BLOCK 24	-9.025	-9.025	0.000	-4.656	0.000	-4.656	-1.109	9.025	9.025	0.000	5.764	0.000	5.764	74.009	1.000	0.000	1.000	0.000
BLOCK 25	-9.025	-9.025	0.000	-5.764	0.000	-5.764	-1.139	9.025	9.025	0.000	6.903	0.000	6.903	150.010	1.000	0.000	1.000	0.000
BLOCK 26	-9.025	-9.025	0.000	-6.903	0.000	-6.903	-1.169	9.025	9.025	0.000	8.071	0.000	8.071	239.853	1.000	0.000	1.000	0.000
BLOCK 27	-9.025	-9.025	0.000	-8.071	0.000	-8.071	-1.199	9.025	9.025	0.000	9.270	0.000	9.270	343.899	1.000	0.000	1.000	0.000
BLOCK 28	-9.025	-9.025	0.000	-9.270	0.000	-9.270	-1.229	9.025	9.025	0.000	10.498	0.000	10.498	462.508	1.000	0.000	1.000	0.000
							-19.433											

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-39.541	0.000	0.000	0.000	39.532	0.000	0.278			0.000	0.000	
BLOCK 2	-39.532	0.000	-0.278	-13.328	39.601	-0.337	0.506			-13.328	-0.337	
BLOCK 3	-39.601	-0.337	-0.506	-29.059	39.724	-0.733	0.649			-15.731	-0.396	
BLOCK 4	-39.724	-0.733	-0.649	-45.871	39.903	-1.154	0.634			-16.812	-0.421	
BLOCK 5	-39.903	-1.154	-0.634	-63.342	40.137	-1.589	0.699			-17.472	-0.435	
BLOCK 6	-40.137	-1.589	-0.699	-81.545	40.421	-2.039	0.696			-18.202	-0.450	
BLOCK 7	-40.421	-2.039	-0.696	-100.389	40.750	-2.502	0.748			-18.845	-0.462	
BLOCK 8	-40.750	-2.502	-0.748	-119.908	41.118	-2.977	0.755			-19.518	-0.475	
BLOCK 9	-41.118	-2.977	-0.755	-140.037	41.518	-3.461	0.806			-20.130	-0.485	
BLOCK 10	-41.518	-3.461	-0.806	-160.757	41.941	-3.955	0.823			-20.720	-0.494	
BLOCK 11	-41.941	-3.955	-0.823	-181.980	42.379	-4.456	0.879			-21.223	-0.501	
BLOCK 12	-42.379	-4.456	-0.879	-203.619	42.821	-4.962	0.908			-21.639	-0.505	
BLOCK 13	-42.821	-4.962	-0.908	-225.525	43.255	-5.468	0.976			-21.906	-0.506	
BLOCK 14	-43.255	-5.468	-0.976	-247.517	43.669	-5.972	1.027			-21.992	-0.504	
BLOCK 15	-43.669	-5.972	-1.027	-269.335	44.054	-6.467	1.123			-21.818	-0.495	
BLOCK 16	-44.054	-6.467	-1.123	-290.650	44.401	-6.947	1.214			-21.315	-0.480	
BLOCK 17	-44.401	-6.947	-1.214	-311.037	44.708	-7.403	1.361			-20.387	-0.456	
BLOCK 18	-44.708	-7.403	-1.361	-330.001	44.988	-7.825	1.514			-18.964	-0.422	
BLOCK 19	-44.988	-7.825	-1.514	-336.552	45.217	-7.969	0.534			-6.551	-0.145	
BLOCK 20	-45.217	-7.969	-0.534	-324.364	45.487	-7.701	1.497	0.033	1.886	12.187	0.268	0.395
BLOCK 21	-45.487	-7.701	-1.497	-300.134	45.757	-7.172	2.541	0.056	3.178	24.230	0.530	1.059
BLOCK 22	-45.757	-7.172	-2.541	-263.501	46.027	-6.376	3.565	0.077	4.428	36.633	0.796	1.983
BLOCK 23	-46.027	-6.376	-3.565	-214.106	46.297	-5.309	4.668	0.101	5.758	49.396	1.067	3.181
BLOCK 24	-46.297	-5.309	-4.668	-151.587	46.567	-3.967	5.752	0.124	7.041	62.518	1.343	4.640
BLOCK 25	-46.567	-3.967	-5.752	-75.586	46.837	-2.344	6.915	0.148	8.399	76.001	1.623	6.374
BLOCK 26	-46.837	-2.344	-6.915	14.257	47.107	-0.437	8.059	0.171	9.708	89.844	1.907	8.369
BLOCK 27	-47.107	-0.437	-8.059	118.303	47.377	1.760	9.282	0.196	11.085	104.046	2.196	10.633
BLOCK 28	-47.377	1.760	-9.282	236.912	47.647	4.249	10.486	0.220	12.412	118.609	2.489	13.152

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90763-39
FILE: ARCH201-DISC4
PRINT: ALT P
MARCH 21, 1991

BETA = 5 DEGREES
FILL HEIGHTH H=20.0 FEET
V=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF TO STONE 10, 40 PCF STONES 11-21, 20 PCF STONES 22-28
ADDED 1,244 POUNDS AT TOP

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-30.606	0.000	30.606	0.000	0.000	0.000	20.000	-1.200	0.000	30.606	1.335	-30.577	0.668	0.667	0.029	0.000	0.000	2.500
BLOCK 2	-30.606	-1.335	30.577	-0.668	-0.667	-0.029	20.087	-2.401	5.000	30.693	4.006	-30.431	0.894	0.886	0.117	-8.456	2.500	7.500
BLOCK 3	-30.693	-4.006	30.431	-0.894	-0.886	-0.117	20.261	-2.394	10.000	30.820	6.671	-30.089	1.039	1.014	0.225	-18.764	7.500	12.500
BLOCK 4	-30.820	-6.671	30.089	-1.039	-1.014	-0.225	20.520	-2.378	15.000	30.991	9.319	-29.556	1.025	0.977	0.308	-29.600	12.500	17.500
BLOCK 5	-30.991	-9.319	29.556	-1.025	-0.977	-0.308	20.862	-2.352	20.000	31.205	11.942	-28.829	1.095	1.011	0.419	-40.557	17.500	22.500
BLOCK 6	-31.205	-11.942	28.829	-1.095	-1.011	-0.419	21.284	-2.315	25.000	31.459	14.526	-27.905	1.095	0.971	0.506	-51.732	22.500	27.500
BLOCK 7	-31.459	-14.526	27.905	-1.095	-0.971	-0.506	21.784	-2.264	30.000	31.752	17.060	-26.779	1.154	0.973	0.620	-63.082	27.500	32.500
BLOCK 8	-31.752	-17.060	26.779	-1.154	-0.973	-0.620	22.358	-2.198	35.000	32.078	19.528	-25.449	1.166	0.925	0.710	-74.697	32.500	37.500
BLOCK 9	-32.078	-19.528	25.449	-1.166	-0.925	-0.710	23.001	-2.114	40.000	32.434	21.912	-23.913	1.223	0.902	0.826	-86.599	37.500	42.500
BLOCK 10	-32.434	-21.912	23.913	-1.223	-0.902	-0.826	23.708	-2.012	45.000	32.815	24.194	-22.170	1.244	0.840	0.917	-98.868	42.500	47.500
BLOCK 11	-32.815	-24.194	22.170	-1.244	-0.840	-0.917	24.474	-1.888	50.000	33.216	26.352	-20.220	1.301	0.792	1.032	-111.546	47.500	52.500
BLOCK 12	-33.216	-26.352	20.220	-1.301	-0.792	-1.032	25.293	-1.741	55.000	33.629	28.363	-18.069	1.327	0.713	1.119	-124.706	52.500	57.500
BLOCK 13	-33.629	-28.363	18.069	-1.327	-0.713	-1.119	26.159	-1.570	60.000	34.049	30.202	-15.722	1.384	0.639	1.228	-138.393	57.500	62.500
BLOCK 14	-34.049	-30.202	15.722	-1.384	-0.639	-1.228	27.065	-1.373	65.000	34.469	31.845	-13.191	1.412	0.540	1.304	-152.664	62.500	67.500
BLOCK 15	-34.469	-31.845	13.191	-1.412	-0.540	-1.304	28.005	-1.149	70.000	34.878	33.264	-10.488	1.466	0.441	1.398	-167.555	67.500	72.500
BLOCK 16	-34.878	-33.264	10.488	-1.466	-0.441	-1.398	28.971	-0.900	75.000	35.270	34.434	-7.634	1.491	0.323	1.456	-183.100	72.500	77.500
BLOCK 17	-35.270	-34.434	7.634	-1.491	-0.323	-1.456	29.956	-0.624	80.000	35.633	35.328	-4.651	1.540	0.201	1.527	-199.309	77.500	82.500
BLOCK 18	-35.633	-35.328	4.651	-1.540	-0.201	-1.527	30.952	-0.324	85.000	35.956	35.922	-1.568	1.557	0.068	1.556	-216.177	82.500	87.500
BLOCK 19	-35.956	-35.922	1.568	-1.557	-0.068	-1.556	31.952	0.000	90.000	36.192	36.192	0.000	0.012	0.000	0.012	-225.596	87.500	90.000
BLOCK 20	-36.192	-36.192	0.000	-0.012	0.000	-0.012	32.952	0.000	90.000	36.462	36.462	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 21	-36.462	-36.462	0.000	0.012	0.000	0.012	33.952	0.000	90.000	36.732	36.732	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 22	-36.732	-36.732	0.000	-0.012	0.000	-0.012	34.952	0.000	90.000	37.002	37.002	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 23	-37.002	-37.002	0.000	0.012	0.000	0.012	35.952	0.000	90.000	37.272	37.272	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 24	-37.272	-37.272	0.000	-0.012	0.000	-0.012	36.952	0.000	90.000	37.542	37.542	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 25	-37.542	-37.542	0.000	0.012	0.000	0.012	37.952	0.000	90.000	37.812	37.812	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 26	-37.812	-37.812	0.000	-0.012	0.000	-0.012	38.952	0.000	90.000	38.082	38.082	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 27	-38.082	-38.082	0.000	0.012	0.000	0.012	39.952	0.000	90.000	38.352	38.352	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 28	-38.352	-38.352	0.000	-0.012	0.000	-0.012	40.952	0.000	90.000	38.622	38.622	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000

-31.197
38.622

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS

AM	AO R(1)	AQ R(1V)	AS R(1H)	AU FRIC(1)	AW FRIC(1V)	AY FRIC(1H)	BA Load(H)	BC R(2)	BE R(2V)	BG R(2H)	BI FRIC(2)	BK FRIC(2V)	BM FRIC(2H)	BO M(cgH)	BQ SIN ALPHA 1	BS COS ALPHA 1	BU SIN ALPHA 2	BW COS ALPHA 2
BLOCK 1	-10.179	0.000	10.179	0.000	0.000	0.000	0.000	10.169	0.444	-10.160	-0.444	-0.444	-0.019	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-10.169	-0.444	10.160	0.444	0.444	0.019	-0.053	10.156	1.326	-10.069	-0.442	-0.438	-0.058	-5.478	0.044	0.999	0.131	0.991
BLOCK 3	-10.156	-1.326	10.069	0.442	0.438	0.058	-0.106	10.165	2.200	-9.924	-0.447	-0.436	-0.097	-11.523	0.131	0.991	0.216	0.976
BLOCK 4	-10.165	-2.200	9.924	0.447	0.436	0.097	-0.159	10.198	3.067	-9.726	-0.451	-0.430	-0.136	-18.151	0.216	0.976	0.301	0.954
BLOCK 5	-10.198	-3.067	9.726	0.451	0.430	0.136	-0.214	10.251	3.923	-9.471	-0.461	-0.426	-0.177	-25.365	0.301	0.954	0.383	0.924
BLOCK 6	-10.251	-3.923	9.471	0.461	0.426	0.177	-0.270	10.326	4.768	-9.160	-0.472	-0.419	-0.218	-33.161	0.383	0.924	0.462	0.887
BLOCK 7	-10.326	-4.768	9.160	0.472	0.419	0.218	-0.327	10.421	5.599	-8.789	-0.488	-0.412	-0.262	-41.518	0.462	0.887	0.537	0.843
BLOCK 8	-10.421	-5.599	8.789	0.488	0.412	0.262	-0.385	10.534	6.413	-8.358	-0.507	-0.402	-0.309	-50.411	0.537	0.843	0.609	0.793
BLOCK 9	-10.534	-6.413	8.358	0.507	0.402	0.309	-0.444	10.667	7.206	-7.864	-0.530	-0.391	-0.358	-59.801	0.609	0.793	0.676	0.737
BLOCK 10	-10.667	-7.206	7.864	0.530	0.391	0.358	-0.503	10.817	7.975	-7.308	-0.559	-0.378	-0.412	-69.648	0.676	0.737	0.737	0.676
BLOCK 11	-10.817	-7.975	7.308	0.559	0.378	0.412	-0.750	10.869	8.623	-6.617	-0.445	-0.271	-0.353	-80.372	0.737	0.676	0.793	0.609
BLOCK 12	-10.869	-8.623	6.617	0.445	0.271	0.353	-0.829	10.801	9.109	-5.803	-0.401	-0.215	-0.338	-90.145	0.793	0.609	0.843	0.537
BLOCK 13	-10.801	-9.109	5.803	0.401	0.215	0.338	-0.906	10.688	9.481	-4.935	-0.338	-0.156	-0.300	-99.086	0.843	0.537	0.887	0.462
BLOCK 14	-10.688	-9.481	4.935	0.338	0.156	0.300	-0.981	10.531	9.729	-4.030	-0.242	-0.093	-0.224	-106.738	0.887	0.462	0.924	0.383
BLOCK 15	-10.531	-9.729	4.030	0.242	0.093	0.224	-1.053	10.330	9.852	-3.106	-0.099	-0.030	-0.095	-112.483	0.924	0.383	0.954	0.301
BLOCK 16	-10.330	-9.852	3.106	0.099	0.030	0.095	-1.119	10.098	9.859	-2.186	0.106	0.023	0.104	-115.541	0.954	0.301	0.976	0.216
BLOCK 17	-10.098	-9.859	2.186	-0.106	-0.023	-0.104	-1.180	9.869	9.785	-1.288	0.390	0.051	0.386	-114.978	0.976	0.216	0.991	0.131
BLOCK 18	-9.869	-9.785	1.288	-0.390	-0.051	-0.386	-1.233	9.710	9.701	-0.424	0.756	0.033	0.755	-109.768	0.991	0.131	0.999	0.044
BLOCK 19	-9.710	-9.701	0.424	-0.756	-0.033	-0.755	-1.278	9.668	9.668	0.000	1.610	0.000	1.610	-95.575	0.999	0.044	1.000	0.000
BLOCK 20	-9.668	-9.668	0.000	-1.610	0.000	-1.610	-1.318	9.668	9.668	0.000	2.928	0.000	2.928	-68.350	1.000	0.000	1.000	0.000
BLOCK 21	-9.668	-9.668	0.000	-2.928	0.000	-2.928	-1.358	9.668	9.668	0.000	4.286	0.000	4.286	-25.068	1.000	0.000	1.000	0.000
BLOCK 22	-9.668	-9.668	0.000	-4.286	0.000	-4.286	-0.699	9.668	9.668	0.000	4.985	0.000	4.985	30.557	1.000	0.000	1.000	0.000
BLOCK 23	-9.668	-9.668	0.000	-4.985	0.000	-4.985	-0.719	9.668	9.668	0.000	5.704	0.000	5.704	94.690	1.000	0.000	1.000	0.000
BLOCK 24	-9.668	-9.668	0.000	-5.704	0.000	-5.704	-0.739	9.668	9.668	0.000	6.443	0.000	6.443	167.572	1.000	0.000	1.000	0.000
BLOCK 25	-9.668	-9.668	0.000	-6.443	0.000	-6.443	-0.759	9.668	9.668	0.000	7.202	0.000	7.202	249.442	1.000	0.000	1.000	0.000
BLOCK 26	-9.668	-9.668	0.000	-7.202	0.000	-7.202	-0.779	9.668	9.668	0.000	7.981	0.000	7.981	340.540	1.000	0.000	1.000	0.000
BLOCK 27	-9.668	-9.668	0.000	-7.981	0.000	-7.981	-0.799	9.668	9.668	0.000	8.780	0.000	8.780	441.107	1.000	0.000	1.000	0.000
BLOCK 28	-9.668	-9.668	0.000	-8.780	0.000	-8.780	-0.819	9.668	9.668	0.000	9.599	0.000	9.599	551.382	1.000	0.000	1.000	0.000
							-19.778											

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES

FILL, 20 FEET, PASSIVE LOADING 1

CA CB CC CD CE CF CG CH CI CJ CK CL CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-40.785	0.000	0.000	0.000	40.775	0.000	0.224			0.000	0.000	
BLOCK 2	-40.775	0.000	-0.224	-13.934	40.849	-0.341	0.451			-13.934	-0.341	
BLOCK 3	-40.849	-0.341	-0.451	-30.287	40.985	-0.740	0.592			-16.352	-0.399	
BLOCK 4	-40.985	-0.740	-0.592	-47.751	41.189	-1.164	0.574			-17.464	-0.424	
BLOCK 5	-41.189	-1.164	-0.574	-65.923	41.456	-1.602	0.633			-18.172	-0.438	
BLOCK 6	-41.456	-1.602	-0.633	-84.894	41.786	-2.056	0.623			-18.971	-0.454	
BLOCK 7	-41.786	-2.056	-0.623	-104.600	42.172	-2.524	0.666			-19.706	-0.467	
BLOCK 8	-42.172	-2.524	-0.666	-125.108	42.613	-3.005	0.659			-20.508	-0.481	
BLOCK 9	-42.613	-3.005	-0.659	-146.400	43.101	-3.499	0.693			-21.292	-0.494	
BLOCK 10	-43.101	-3.499	-0.693	-168.516	43.632	-4.006	0.685			-22.117	-0.507	
BLOCK 11	-43.632	-4.006	-0.685	-191.918	44.085	-4.537	0.856			-23.402	-0.531	
BLOCK 12	-44.085	-4.537	-0.856	-214.851	44.430	-5.053	0.926			-22.933	-0.516	
BLOCK 13	-44.430	-5.053	-0.926	-237.479	44.738	-5.559	1.046			-22.628	-0.506	
BLOCK 14	-44.738	-5.559	-1.046	-259.402	44.999	-6.046	1.169			-21.923	-0.487	
BLOCK 15	-44.999	-6.046	-1.169	-280.038	45.208	-6.502	1.367			-20.636	-0.456	
BLOCK 16	-45.208	-6.502	-1.367	-298.642	45.368	-6.912	1.598			-18.604	-0.410	
BLOCK 17	-45.368	-6.912	-1.598	-314.287	45.502	-7.256	1.930			-15.646	-0.344	
BLOCK 18	-45.502	-7.256	-1.930	-325.945	45.666	-7.512	2.313			-11.658	-0.255	
BLOCK 19	-45.666	-7.512	-2.313	-321.171	45.860	-7.407	1.622			4.775	0.104	
BLOCK 20	-45.860	-7.407	-1.622	-293.946	46.130	-6.817	2.915	0.063	3.616	27.225	0.590	0.755
BLOCK 21	-46.130	-6.817	-2.915	-250.664	46.400	-5.884	4.298	0.093	5.293	43.282	0.933	1.858
BLOCK 22	-46.400	-5.884	-4.298	-195.039	46.670	-4.693	4.972	0.107	6.082	55.625	1.192	3.122
BLOCK 23	-46.670	-4.693	-4.972	-130.906	46.940	-3.326	5.716	0.122	6.943	64.133	1.366	4.562
BLOCK 24	-46.940	-3.326	-5.716	-58.024	47.210	-1.782	6.431	0.136	7.757	72.882	1.544	6.167
BLOCK 25	-47.210	-1.782	-6.431	23.846	47.480	-0.058	7.214	0.152	8.640	81.870	1.724	7.949
BLOCK 26	-47.480	-0.058	-7.214	114.944	47.750	1.850	7.969	0.167	9.474	91.098	1.908	9.897
BLOCK 27	-47.750	1.850	-7.969	215.511	48.020	3.944	8.793	0.183	10.376	100.567	2.094	12.023
BLOCK 28	-48.020	3.944	-8.793	325.786	48.290	6.228	9.587	0.199	11.229	110.275	2.284	14.315

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCH203-DISC4
PRINT: ALT P
MARCH 21, 1991

BETA = 5 DEGREES
FILL HEIGHTH H=20.0 FEET
V=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF TO STONE 10, 50 PCF STONES 11-21, 20 PCF STONES 22-28
ADDED 2,942 POUNDS AT TOP

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL, 20 FEET, PASSIVE LOADING 3

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	R	Load(V)	DELTA	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	-30.606	0.000	30.606	0.000	0.000	0.000	20.000	-1.200	0.000	30.606	1.335	-30.577	0.668	0.667	0.029	0.000	0.000	2.500
BLOCK 2	-30.606	-1.335	30.577	-0.668	-0.667	-0.029	20.087	-2.401	5.000	30.693	4.006	-30.431	0.894	0.886	0.117	-8.456	2.500	7.500
BLOCK 3	-30.693	-4.006	30.431	-0.894	-0.886	-0.117	20.261	-2.394	10.000	30.820	6.671	-30.089	1.039	1.014	0.225	-18.764	7.500	12.500
BLOCK 4	-30.820	-6.671	30.089	-1.039	-1.014	-0.225	20.520	-2.378	15.000	30.991	9.319	-29.556	1.025	0.977	0.308	-29.600	12.500	17.500
BLOCK 5	-30.991	-9.319	29.556	-1.025	-0.977	-0.308	20.862	-2.352	20.000	31.205	11.942	-28.829	1.095	1.011	0.419	-40.557	17.500	22.500
BLOCK 6	-31.205	-11.942	28.829	-1.095	-1.011	-0.419	21.284	-2.315	25.000	31.459	14.526	-27.905	1.095	0.971	0.506	-51.732	22.500	27.500
BLOCK 7	-31.459	-14.526	27.905	-1.095	-0.971	-0.506	21.784	-2.264	30.000	31.752	17.060	-26.779	1.154	0.973	0.620	-63.082	27.500	32.500
BLOCK 8	-31.752	-17.060	26.779	-1.154	-0.973	-0.620	22.358	-2.198	35.000	32.078	19.528	-25.449	1.166	0.925	0.710	-74.697	32.500	37.500
BLOCK 9	-32.078	-19.528	25.449	-1.166	-0.925	-0.710	23.001	-2.114	40.000	32.434	21.912	-23.913	1.223	0.902	0.826	-86.599	37.500	42.500
BLOCK 10	-32.434	-21.912	23.913	-1.223	-0.902	-0.826	23.708	-2.012	45.000	32.815	24.194	-22.170	1.244	0.840	0.917	-98.868	42.500	47.500
BLOCK 11	-32.815	-24.194	22.170	-1.244	-0.840	-0.917	24.474	-1.888	50.000	33.216	26.352	-20.220	1.301	0.792	1.032	-111.546	47.500	52.500
BLOCK 12	-33.216	-26.352	20.220	-1.301	-0.792	-1.032	25.293	-1.741	55.000	33.629	28.363	-18.069	1.327	0.713	1.119	-124.706	52.500	57.500
BLOCK 13	-33.629	-28.363	18.069	-1.327	-0.713	-1.119	26.159	-1.570	60.000	34.049	30.202	-15.722	1.384	0.639	1.228	-138.393	57.500	62.500
BLOCK 14	-34.049	-30.202	15.722	-1.384	-0.639	-1.228	27.065	-1.373	65.000	34.469	31.845	-13.191	1.412	0.540	1.304	-152.664	62.500	67.500
BLOCK 15	-34.469	-31.845	13.191	-1.412	-0.540	-1.304	28.005	-1.149	70.000	34.878	33.264	-10.488	1.466	0.441	1.398	-167.555	67.500	72.500
BLOCK 16	-34.878	-33.264	10.488	-1.466	-0.441	-1.398	28.971	-0.900	75.000	35.270	34.434	-7.634	1.491	0.323	1.456	-183.100	72.500	77.500
BLOCK 17	-35.270	-34.434	7.634	-1.491	-0.323	-1.456	29.956	-0.624	80.000	35.633	35.328	-4.651	1.540	0.201	1.527	-199.309	77.500	82.500
BLOCK 18	-35.633	-35.328	4.651	-1.540	-0.201	-1.527	30.952	-0.324	85.000	35.956	35.922	-1.568	1.557	0.068	1.556	-216.177	82.500	87.500
BLOCK 19	-35.956	-35.922	1.568	-1.557	-0.068	-1.556	31.952	0.000	90.000	36.192	36.192	0.000	0.012	0.000	0.012	-225.596	87.500	90.000
BLOCK 20	-36.192	-36.192	0.000	-0.012	0.000	-0.012	32.952	0.000	90.000	36.462	36.462	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 21	-36.462	-36.462	0.000	0.012	0.000	0.012	33.952	0.000	90.000	36.732	36.732	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 22	-36.732	-36.732	0.000	-0.012	0.000	-0.012	34.952	0.000	90.000	37.002	37.002	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 23	-37.002	-37.002	0.000	0.012	0.000	0.012	35.952	0.000	90.000	37.272	37.272	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 24	-37.272	-37.272	0.000	-0.012	0.000	-0.012	36.952	0.000	90.000	37.542	37.542	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 25	-37.542	-37.542	0.000	0.012	0.000	0.012	37.952	0.000	90.000	37.812	37.812	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 26	-37.812	-37.812	0.000	-0.012	0.000	-0.012	38.952	0.000	90.000	38.082	38.082	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000
BLOCK 27	-38.082	-38.082	0.000	0.012	0.000	0.012	39.952	0.000	90.000	38.352	38.352	0.000	0.012	0.000	0.012	-225.596	90.000	90.000
BLOCK 28	-38.352	-38.352	0.000	-0.012	0.000	-0.012	40.952	0.000	90.000	38.622	38.622	0.000	-0.012	0.000	-0.012	-225.596	90.000	90.000

-31.197
38.622

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

AM AN	AO AP R(1)	AQ AR R(1V)	AS AT R(1H)	AU AV FRIC(1)	AW AX FRIC(1V)	AY AZ FRIC(1H)	BA BB Load(H)	BC BD R(2)	BE BF R(2V)	BG BH R(2H)	BI BJ FRIC(2)	BK BL FRIC(2V)	BM BN FRIC(2H)	BO BP M(cgH)	BQ BR SIN ALPHA 1	BS BT COS ALPHA 1	BU BV SIN ALPHA 2	BW BX COS ALPHA 2
BLOCK 1	-11.877	0.000	11.877	0.000	0.000	0.000	0.000	11.866	0.518	-11.854	-0.518	-0.518	-0.023	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-11.866	-0.518	11.854	0.518	0.518	0.023	-0.053	11.858	1.548	-11.757	-0.517	-0.513	-0.067	-6.305	0.044	0.999	0.131	0.991
BLOCK 3	-11.858	-1.548	11.757	0.517	0.513	0.067	-0.106	11.887	2.573	-11.605	-0.525	-0.512	-0.114	-13.198	0.131	0.991	0.216	0.976
BLOCK 4	-11.887	-2.573	11.605	0.525	0.512	0.114	-0.159	11.952	3.594	-11.399	-0.534	-0.509	-0.160	-20.718	0.216	0.976	0.301	0.954
BLOCK 5	-11.952	-3.594	11.399	0.534	0.509	0.160	-0.214	12.052	4.612	-11.135	-0.551	-0.509	-0.211	-28.888	0.301	0.954	0.383	0.924
BLOCK 6	-12.052	-4.612	11.135	0.551	0.509	0.211	-0.270	12.189	5.628	-10.812	-0.572	-0.507	-0.264	-37.733	0.383	0.924	0.462	0.887
BLOCK 7	-12.189	-5.628	10.812	0.572	0.507	0.264	-0.327	12.362	6.642	-10.426	-0.601	-0.507	-0.323	-47.266	0.462	0.887	0.537	0.843
BLOCK 8	-12.362	-6.642	10.426	0.601	0.507	0.323	-0.385	12.574	7.655	-9.976	-0.638	-0.506	-0.388	-57.509	0.537	0.843	0.609	0.793
BLOCK 9	-12.574	-7.655	9.976	0.638	0.506	0.388	-0.444	12.828	8.666	-9.458	-0.686	-0.505	-0.463	-68.485	0.609	0.793	0.676	0.737
BLOCK 10	-12.828	-8.666	9.458	0.686	0.505	0.463	-0.503	13.125	9.676	-8.867	-0.747	-0.505	-0.551	-80.238	0.676	0.737	0.737	0.676
BLOCK 11	-13.125	-9.676	8.867	0.747	0.505	0.551	-0.937	13.240	10.504	-8.060	-0.530	-0.323	-0.420	-93.768	0.737	0.676	0.793	0.609
BLOCK 12	-13.240	-10.504	8.060	0.530	0.323	0.420	-1.036	13.131	11.074	-7.055	-0.461	-0.248	-0.389	-105.622	0.793	0.609	0.843	0.537
BLOCK 13	-13.131	-11.074	7.055	0.461	0.248	0.389	-1.133	12.958	11.493	-5.983	-0.370	-0.171	-0.329	-116.294	0.843	0.537	0.887	0.462
BLOCK 14	-12.958	-11.493	5.983	0.370	0.171	0.329	-1.226	12.723	11.754	-4.869	-0.234	-0.090	-0.216	-125.191	0.887	0.462	0.924	0.383
BLOCK 15	-12.723	-11.754	4.869	0.234	0.090	0.216	-1.316	12.429	11.854	-3.738	-0.033	-0.010	-0.032	-131.488	0.924	0.383	0.954	0.301
BLOCK 16	-12.429	-11.854	3.738	0.033	0.010	0.032	-1.399	12.096	11.809	-2.618	0.254	0.055	0.248	-134.137	0.954	0.301	0.976	0.216
BLOCK 17	-12.096	-11.809	2.618	-0.254	-0.055	-0.248	-1.475	11.770	11.670	-1.536	0.647	0.084	0.641	-131.877	0.976	0.216	0.991	0.131
BLOCK 18	-11.770	-11.670	1.536	-0.647	-0.084	-0.641	-1.542	11.546	11.535	-0.504	1.151	0.050	1.150	-123.335	0.991	0.131	0.999	0.044
BLOCK 19	-11.546	-11.535	0.504	-1.151	-0.050	-1.150	-1.598	11.485	11.485	0.000	2.244	0.000	2.244	-102.964	0.999	0.044	1.000	0.000
BLOCK 20	-11.485	-11.485	0.000	-2.244	0.000	-2.244	-1.648	11.485	11.485	0.000	3.892	0.000	3.892	-66.149	1.000	0.000	1.000	0.000
BLOCK 21	-11.485	-11.485	0.000	-3.892	0.000	-3.892	-1.698	11.485	11.485	0.000	5.589	0.000	5.589	-9.263	1.000	0.000	1.000	0.000
BLOCK 22	-11.485	-11.485	0.000	-5.589	0.000	-5.589	-0.699	11.485	11.485	0.000	6.288	0.000	6.288	62.002	1.000	0.000	1.000	0.000
BLOCK 23	-11.485	-11.485	0.000	-6.288	0.000	-6.288	-0.719	11.485	11.485	0.000	7.007	0.000	7.007	141.776	1.000	0.000	1.000	0.000
BLOCK 24	-11.485	-11.485	0.000	-7.007	0.000	-7.007	-0.739	11.485	11.485	0.000	7.746	0.000	7.746	230.299	1.000	0.000	1.000	0.000
BLOCK 25	-11.485	-11.485	0.000	-7.746	0.000	-7.746	-0.759	11.485	11.485	0.000	8.505	0.000	8.505	327.810	1.000	0.000	1.000	0.000
BLOCK 26	-11.485	-11.485	0.000	-8.505	0.000	-8.505	-0.779	11.485	11.485	0.000	9.284	0.000	9.284	434.549	1.000	0.000	1.000	0.000
BLOCK 27	-11.485	-11.485	0.000	-9.284	0.000	-9.284	-0.799	11.485	11.485	0.000	10.084	0.000	10.084	550.757	1.000	0.000	1.000	0.000
BLOCK 28	-11.485	-11.485	0.000	-10.084	0.000	-10.084	-0.819	11.485	11.485	0.000	10.903	0.000	10.903	676.673	1.000	0.000	1.000	0.000
							-22.780											

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

FILL, 20 FEET, PASSIVE LOADING 3

CM CN CO CP CQ CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-42.483	0.000	0.000	0.000	42.471	0.000	0.150			0.000	0.000	
BLOCK 2	-42.471	0.000	-0.150	-14.761	42.552	-0.347	0.376			-14.761	-0.347	
BLOCK 3	-42.552	-0.347	-0.376	-31.962	42.707	-0.750	0.514			-17.201	-0.403	
BLOCK 4	-42.707	-0.750	-0.514	-50.317	42.943	-1.177	0.491			-18.355	-0.427	
BLOCK 5	-42.943	-1.177	-0.491	-69.445	43.257	-1.619	0.544			-19.128	-0.442	
BLOCK 6	-43.257	-1.619	-0.544	-89.465	43.648	-2.078	0.524			-20.020	-0.459	
BLOCK 7	-43.648	-2.078	-0.524	-110.348	44.114	-2.551	0.553			-20.883	-0.473	
BLOCK 8	-44.114	-2.551	-0.553	-132.206	44.653	-3.041	0.528			-21.859	-0.490	
BLOCK 9	-44.653	-3.041	-0.528	-155.084	45.262	-3.546	0.538			-22.878	-0.505	
BLOCK 10	-45.262	-3.546	-0.538	-179.107	45.940	-4.069	0.497			-24.023	-0.523	
BLOCK 11	-45.940	-4.069	-0.497	-205.314	46.456	-4.633	0.771			-26.208	-0.564	
BLOCK 12	-46.456	-4.633	-0.771	-230.329	46.760	-5.168	0.865			-25.014	-0.535	
BLOCK 13	-46.760	-5.168	-0.865	-254.686	47.007	-5.686	1.014			-24.358	-0.518	
BLOCK 14	-47.007	-5.686	-1.014	-277.855	47.191	-6.177	1.177			-23.169	-0.491	
BLOCK 15	-47.191	-6.177	-1.177	-299.043	47.308	-6.625	1.433			-21.188	-0.448	
BLOCK 16	-47.308	-6.625	-1.433	-317.237	47.366	-7.009	1.745			-18.194	-0.384	
BLOCK 17	-47.366	-7.009	-1.745	-331.187	47.403	-7.304	2.187			-13.950	-0.294	
BLOCK 18	-47.403	-7.304	-2.187	-339.512	47.502	-7.479	2.709			-8.326	-0.175	
BLOCK 19	-47.502	-7.479	-2.709	-328.560	47.677	-7.249	2.257			10.953	0.230	
BLOCK 20	-47.677	-7.249	-2.257	-291.745	47.947	-6.481	3.879	0.081	4.626	36.815	0.768	0.965
BLOCK 21	-47.947	-6.481	-3.879	-234.859	48.217	-5.302	5.602	0.116	6.627	56.886	1.180	2.340
BLOCK 22	-48.217	-5.302	-5.602	-163.594	48.487	-3.832	6.276	0.129	7.375	71.266	1.470	3.868
BLOCK 23	-48.487	-3.832	-6.276	-83.820	48.757	-2.196	7.020	0.144	8.193	79.774	1.636	5.560
BLOCK 24	-48.757	-2.196	-7.020	4.703	49.027	-0.390	7.734	0.158	8.965	88.522	1.806	7.407
BLOCK 25	-49.027	-0.390	-7.734	102.214	49.297	1.588	8.518	0.173	9.803	97.511	1.978	9.421
BLOCK 26	-49.297	1.588	-8.518	208.953	49.567	3.741	9.272	0.187	10.595	106.739	2.153	11.590
BLOCK 27	-49.567	3.741	-9.272	325.161	49.837	6.073	10.096	0.203	11.452	116.208	2.332	13.925
BLOCK 28	-49.837	6.073	-10.096	451.077	50.107	8.586	10.890	0.217	12.262	125.916	2.513	16.415

STAPLE BEND TUNNEL
ARCH ANALYSIS WITH EXTERNAL LOAD
JOB NO. 90783-39
FILE: ARCHL5R0-DISC1
PRINT: ALT P
NOVEMBER 26, 1990

BETA = 5 DEGREES
FILL HEIGHTH H=5 LEFT/0 RIGHT
W=0.270
GAMMA=120 PCF
FLUID GAMMA=30 PCF

COLUMNS A TO AL
VERTICAL LOAD ANALYSIS
PAGE 1

FILL, 5' LEFT, 0' RIGHT
PAGE 38 OF
10-1

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL

	F(1)	F(1V)	F(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	H	Load(V)	DELTA
BLOCK 1	-3.095	0.000	3.095	0.000	0.000	0.000	0.000	0.000	0.000
BLOCK 2	-3.095	-0.135	3.092	-0.068	-0.067	-0.003	0.087	-0.010	5.000
BLOCK 3	-3.183	-0.415	3.155	0.508	0.504	0.066	0.261	-0.031	10.000
BLOCK 4	-3.309	-0.716	3.231	0.041	0.040	0.009	0.520	-0.060	15.000
BLOCK 5	-3.480	-1.046	3.319	0.264	0.251	0.079	0.862	-0.097	20.000
BLOCK 6	-3.694	-1.414	3.413	0.038	0.035	0.015	1.284	-0.140	25.000
BLOCK 7	-3.949	-1.823	3.503	0.163	0.144	0.075	1.784	-0.185	30.000
BLOCK 8	-4.241	-2.279	3.577	-0.001	-0.001	-0.001	2.358	-0.232	35.000
BLOCK 9	-4.567	-2.781	3.624	0.078	0.062	0.048	3.001	-0.276	40.000
BLOCK 10	-4.924	-3.326	3.630	-0.061	-0.045	-0.041	3.708	-0.315	45.000
BLOCK 11	-5.305	-3.911	3.584	-0.007	-0.005	-0.005	4.474	-0.345	50.000
BLOCK 12	-5.705	-4.526	3.473	-0.133	-0.081	-0.106	5.293	-0.364	55.000
BLOCK 13	-6.119	-5.160	3.287	-0.095	-0.051	-0.080	6.159	-0.370	60.000
BLOCK 14	-6.539	-5.800	3.019	-0.212	-0.098	-0.188	7.065	-0.358	65.000
BLOCK 15	-6.958	-6.428	2.663	-0.182	-0.070	-0.168	8.005	-0.329	70.000
BLOCK 16	-7.368	-7.027	2.216	-0.292	-0.088	-0.279	8.971	-0.279	75.000
BLOCK 17	-7.759	-7.575	1.679	-0.263	-0.057	-0.257	9.956	-0.207	80.000
BLOCK 18	-8.122	-8.053	1.060	-0.365	-0.048	-0.362	10.952	-0.115	85.000
BLOCK 19	-8.445	-8.437	0.368	-0.330	-0.014	-0.330	11.952	0.000	90.000
BLOCK 20	-8.707	-8.707	0.000	-0.039	0.000	-0.039	12.952	0.000	90.000
BLOCK 21	-8.977	-8.977	0.000	0.039	0.000	0.039	13.952	0.000	90.000
BLOCK 22	-9.247	-9.247	0.000	-0.039	0.000	-0.039	14.952	0.000	90.000
BLOCK 23	-9.517	-9.517	0.000	0.039	0.000	0.039	15.952	0.000	90.000
BLOCK 24	-9.787	-9.787	0.000	-0.039	0.000	-0.039	16.952	0.000	90.000
BLOCK 25	-10.057	-10.057	0.000	0.039	0.000	0.039	17.952	0.000	90.000
BLOCK 26	-10.327	-10.327	0.000	-0.039	0.000	-0.039	18.952	0.000	90.000
BLOCK 27	-10.597	-10.597	0.000	0.039	0.000	0.039	19.952	0.000	90.000
BLOCK 28	-10.867	-10.867	0.000	-0.039	0.000	-0.039	20.952	0.000	90.000

	F(2)	F(2V)	F(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgV)	ALPHA(1)	ALPHA(2)
BLOCK 1	3.095	0.135	-3.092	0.068	0.067	0.003	0.000	0.000	2.500
BLOCK 2	3.183	0.415	-3.155	-0.508	-0.504	-0.066	2.448	2.500	7.500
BLOCK 3	3.309	0.716	-3.231	-0.041	-0.040	-0.009	5.505	7.500	12.500
BLOCK 4	3.480	1.046	-3.319	-0.264	-0.251	-0.079	7.213	12.500	17.500
BLOCK 5	3.694	1.414	-3.413	-0.038	-0.035	-0.015	8.920	17.500	22.500
BLOCK 6	3.949	1.823	-3.503	-0.163	-0.144	-0.075	10.094	22.500	27.500
BLOCK 7	4.241	2.279	-3.577	0.001	0.001	0.001	11.082	27.500	32.500
BLOCK 8	4.567	2.781	-3.624	-0.078	-0.062	-0.048	11.640	32.500	37.500
BLOCK 9	4.924	3.326	-3.630	0.061	0.045	0.041	11.913	37.500	42.500
BLOCK 10	5.305	3.911	-3.584	0.007	0.005	0.005	11.758	42.500	47.500
BLOCK 11	5.705	4.526	-3.473	0.133	0.081	0.106	11.245	47.500	52.500
BLOCK 12	6.119	5.160	-3.287	0.095	0.051	0.080	10.279	52.500	57.500
BLOCK 13	6.539	5.800	-3.019	0.212	0.098	0.188	8.895	57.500	62.500
BLOCK 14	6.958	6.428	-2.663	0.182	0.070	0.168	7.030	62.500	67.500
BLOCK 15	7.368	7.027	-2.216	0.292	0.088	0.279	4.706	67.500	72.500
BLOCK 16	7.759	7.575	-1.679	0.263	0.057	0.257	1.890	72.500	77.500
BLOCK 17	8.122	8.053	-1.060	0.365	0.048	0.362	-1.395	77.500	82.500
BLOCK 18	8.445	8.437	-0.368	0.330	0.014	0.330	-5.139	82.500	87.500
BLOCK 19	8.707	8.707	0.000	0.039	0.000	0.039	-7.351	87.500	90.000
BLOCK 20	8.977	8.977	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 21	9.247	9.247	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 22	9.517	9.517	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 23	9.787	9.787	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 24	10.057	10.057	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 25	10.327	10.327	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 26	10.597	10.597	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000
BLOCK 27	10.867	10.867	0.000	0.039	0.000	0.039	-7.351	90.000	90.000
BLOCK 28	11.137	11.137	0.000	-0.039	0.000	-0.039	-7.351	90.000	90.000

-3.712
11.137

COLUMNS AM TO BX
HORIZONTAL LOAD ANALYSIS
PAGE 2

AM AN	AO AP	AQ AR	AS AT	AU AV	AW AX	AY AZ	BA BB	BC BD	BE BF	BG BH	BI BJ	BK BL	BM BN	BO BP	BQ BR	BS BT	BU BV	BW BX
	R(1)	R(1V)	R(1H)	FRIC(1)	FRIC(1V)	FRIC(1H)	Load(H)	R(2)	R(2V)	R(2H)	FRIC(2)	FRIC(2V)	FRIC(2H)	M(cgH)	SIN ALPHA 1	COS ALPHA 1	SIN ALPHA 2	COS ALPHA 2
BLOCK 1	-10.833	0.000	10.833	0.000	0.000	0.000	0.000	10.823	0.472	-10.812	-0.473	-0.472	-0.021	0.000	0.000	1.000	0.044	0.999
BLOCK 2	-10.823	-0.472	10.812	0.473	0.472	0.021	-0.000	10.863	1.618	-10.770	-0.478	-0.474	-0.062	-5.277	0.044	0.999	0.131	0.991
BLOCK 3	-10.863	-1.418	10.770	0.478	0.474	0.062	-0.001	10.984	2.377	-10.724	-0.497	-0.486	-0.108	-10.705	0.131	0.991	0.216	0.976
BLOCK 4	-10.984	-2.377	10.724	0.497	0.486	0.108	-0.004	11.187	3.364	-10.669	-0.525	-0.501	-0.158	-16.423	0.216	0.976	0.301	0.954
BLOCK 5	-11.187	-3.364	10.669	0.525	0.501	0.158	-0.009	11.474	4.391	-10.601	-0.569	-0.526	-0.218	-22.586	0.301	0.954	0.383	0.924
BLOCK 6	-11.474	-4.391	10.601	0.569	0.526	0.218	-0.016	11.852	5.473	-10.513	-0.627	-0.556	-0.289	-29.381	0.383	0.924	0.462	0.887
BLOCK 7	-11.852	-5.473	10.513	0.627	0.556	0.289	-0.027	12.327	6.623	-10.397	-0.705	-0.595	-0.379	-37.021	0.462	0.887	0.537	0.843
BLOCK 8	-12.327	-6.623	10.397	0.705	0.595	0.379	-0.041	12.911	7.860	-10.243	-0.808	-0.641	-0.492	-45.777	0.537	0.843	0.609	0.793
BLOCK 9	-12.911	-7.860	10.243	0.808	0.641	0.492	-0.058	13.615	9.198	-10.038	-0.946	-0.697	-0.639	-55.987	0.609	0.793	0.676	0.737
BLOCK 10	-13.615	-9.198	10.038	0.946	0.697	0.639	-0.079	14.456	10.658	-9.766	-1.129	-0.763	-0.832	-68.094	0.676	0.737	0.737	0.676
BLOCK 11	-14.456	-10.658	9.766	1.129	0.763	0.832	-0.103	15.450	12.257	-9.405	-1.374	-0.837	-1.090	-82.693	0.737	0.676	0.793	0.609
BLOCK 12	-15.450	-12.257	9.405	1.374	0.837	1.090	-0.130	16.613	14.011	-8.926	-1.707	-0.917	-1.440	-100.591	0.793	0.609	0.843	0.537
BLOCK 13	-16.613	-14.011	8.926	1.707	0.917	1.440	-0.160	17.954	15.925	-8.290	-2.159	-0.997	-1.915	-122.904	0.843	0.537	0.887	0.462
BLOCK 14	-17.954	-15.925	8.290	2.159	0.997	1.915	-0.192	19.466	17.984	-7.449	-2.775	-1.062	-2.564	-151.160	0.887	0.462	0.924	0.383
BLOCK 15	-19.466	-17.984	7.449	2.775	1.062	2.564	-0.226	21.108	20.131	-6.347	-3.607	-1.085	-3.440	-187.409	0.924	0.383	0.954	0.301
BLOCK 16	-21.108	-20.131	6.347	3.607	1.085	3.440	-0.260	22.775	22.235	-4.929	-4.710	-1.019	-4.598	-234.289	0.954	0.301	0.976	0.216
BLOCK 17	-22.775	-22.235	4.929	4.710	1.019	4.598	-0.294	24.261	24.053	-3.167	-6.119	-0.799	-6.067	-294.938	0.976	0.216	0.991	0.131
BLOCK 18	-24.261	-24.053	3.167	6.119	0.799	6.067	-0.327	25.217	25.193	-1.100	-7.814	-0.341	-7.806	-372.571	0.991	0.131	0.999	0.044
BLOCK 19	-25.217	-25.193	1.100	7.814	0.341	7.806	-0.359	25.534	25.534	0.000	-8.548	0.000	-8.548	-470.741	0.999	0.044	1.000	0.000
BLOCK 20	-25.534	-25.534	0.000	8.548	0.000	8.548	-0.389	25.534	25.534	0.000	-8.159	0.000	-8.159	-570.983	1.000	0.000	1.000	0.000
BLOCK 21	-25.534	-25.534	0.000	8.159	0.000	8.159	-0.419	25.534	25.534	0.000	-7.741	0.000	-7.741	-666.383	1.000	0.000	1.000	0.000
BLOCK 22	-25.534	-25.534	0.000	7.741	0.000	7.741	-0.449	25.534	25.534	0.000	-7.292	0.000	-7.292	-756.579	1.000	0.000	1.000	0.000
BLOCK 23	-25.534	-25.534	0.000	7.292	0.000	7.292	-0.479	25.534	25.534	0.000	-6.814	0.000	-6.814	-841.213	1.000	0.000	1.000	0.000
BLOCK 24	-25.534	-25.534	0.000	6.814	0.000	6.814	-0.509	25.534	25.534	0.000	-6.305	0.000	-6.305	-919.925	1.000	0.000	1.000	0.000
BLOCK 25	-25.534	-25.534	0.000	6.305	0.000	6.305	-0.539	25.534	25.534	0.000	-5.766	0.000	-5.766	-992.353	1.000	0.000	1.000	0.000
BLOCK 26	-25.534	-25.534	0.000	5.766	0.000	5.766	-0.569	25.534	25.534	0.000	-5.198	0.000	-5.198	-1058.139	1.000	0.000	1.000	0.000
BLOCK 27	-25.534	-25.534	0.000	5.198	0.000	5.198	-0.599	25.534	25.534	0.000	-4.599	0.000	-4.599	-1116.922	1.000	0.000	1.000	0.000
BLOCK 28	-25.534	-25.534	0.000	4.599	0.000	4.599	-0.629	25.534	25.534	0.000	-3.971	0.000	-3.971	-1168.343	1.000	0.000	1.000	0.000

-6.862

COLUMNS CA TO CZ
COMBINED VERTICAL AND HORIZONTAL LOADS
ALL LOADS IN KIPS
MOMENTS IN KIP-INCHES
PAGE 3

CM CN CO CP CO CR CS CT CU CV CW CX CY CZ

CA CB CC CD CE CF CG CH CI CJ CK CL

	R1	c(R1)	FRIC(1)	M(cg)	R2	c(R2)	FRIC(2)	TAN= FRIC(2)/R2	REACTION ANGLE @BASE	DELTA MOMENT	DELTA c	REACTION LINE OFFSET
BLOCK 1	-13.928	0.000	0.000	0.000	13.918	0.000	-0.405			0.000	0.000	
BLOCK 2	-13.918	0.000	0.405	-2.830	14.046	-0.201	-0.986			-2.830	-0.201	
BLOCK 3	-14.046	-0.201	0.986	-5.200	14.293	-0.367	-0.539			-2.370	-0.166	
BLOCK 4	-14.293	-0.367	0.539	-9.209	14.667	-0.641	-0.789			-4.010	-0.273	
BLOCK 5	-14.667	-0.641	0.789	-13.666	15.168	-0.934	-0.607			-4.456	-0.294	
BLOCK 6	-15.168	-0.934	0.607	-19.287	15.801	-1.290	-0.789			-5.621	-0.356	
BLOCK 7	-15.801	-1.290	0.789	-25.939	16.568	-1.692	-0.704			-6.652	-0.401	
BLOCK 8	-16.568	-1.692	0.704	-34.137	17.478	-2.161	-0.887			-8.199	-0.469	
BLOCK 9	-17.478	-2.161	0.887	-44.074	18.539	-2.697	-0.885			-9.937	-0.536	
BLOCK 10	-18.539	-2.697	0.885	-56.336	19.761	-3.317	-1.122			-12.262	-0.621	
BLOCK 11	-19.761	-3.317	1.122	-71.447	21.155	-4.032	-1.241			-15.111	-0.714	
BLOCK 12	-21.155	-4.032	1.241	-90.312	22.731	-4.861	-1.612			-18.864	-0.830	
BLOCK 13	-22.731	-4.861	1.612	-114.009	24.492	-5.829	-1.947			-23.698	-0.968	
BLOCK 14	-24.492	-5.829	1.947	-144.129	26.424	-6.969	-2.593			-30.120	-1.140	
BLOCK 15	-26.424	-6.969	2.593	-182.703	28.476	-8.324	-3.315			-38.574	-1.355	
BLOCK 16	-28.476	-8.324	3.315	-232.400	30.534	-9.951	-4.447			-49.697	-1.628	
BLOCK 17	-30.534	-9.951	4.447	-296.333	32.383	-11.925	-5.754			-63.933	-1.974	
BLOCK 18	-32.383	-11.925	5.754	-377.711	33.662	-14.343	-7.484			-81.378	-2.417	
BLOCK 19	-33.662	-14.343	7.484	-478.093	34.241	-17.274	-8.509			-100.382	-2.932	
BLOCK 20	-34.241	-17.274	8.509	-578.335	34.511	-20.179	-8.198	-0.238	-13.362	-100.242	-2.905	-2.698
BLOCK 21	-34.511	-20.179	8.198	-673.734	34.781	-22.922	-7.702	-0.221	-12.486	-95.399	-2.743	-5.231
BLOCK 22	-34.781	-22.922	7.702	-763.931	35.051	-25.495	-7.331	-0.209	-11.813	-90.197	-2.573	-7.636
BLOCK 23	-35.051	-25.495	7.331	-848.565	35.321	-27.891	-6.775	-0.192	-10.858	-84.634	-2.396	-9.856
BLOCK 24	-35.321	-27.891	6.775	-927.276	35.591	-30.103	-6.344	-0.178	-10.106	-78.711	-2.212	-11.929
BLOCK 25	-35.591	-30.103	6.344	-999.705	35.861	-32.123	-5.728	-0.160	-9.075	-72.429	-2.020	-13.798
BLOCK 26	-35.861	-32.123	5.728	-1065.491	36.131	-33.943	-5.237	-0.145	-8.246	-65.786	-1.821	-15.501
BLOCK 27	-36.131	-33.943	5.237	-1124.274	36.401	-35.558	-4.561	-0.125	-7.141	-58.783	-1.615	-16.982
BLOCK 28	-36.401	-35.558	4.561	-1175.695	36.671	-36.960	-4.009	-0.109	-6.240	-51.421	-1.402	-18.278

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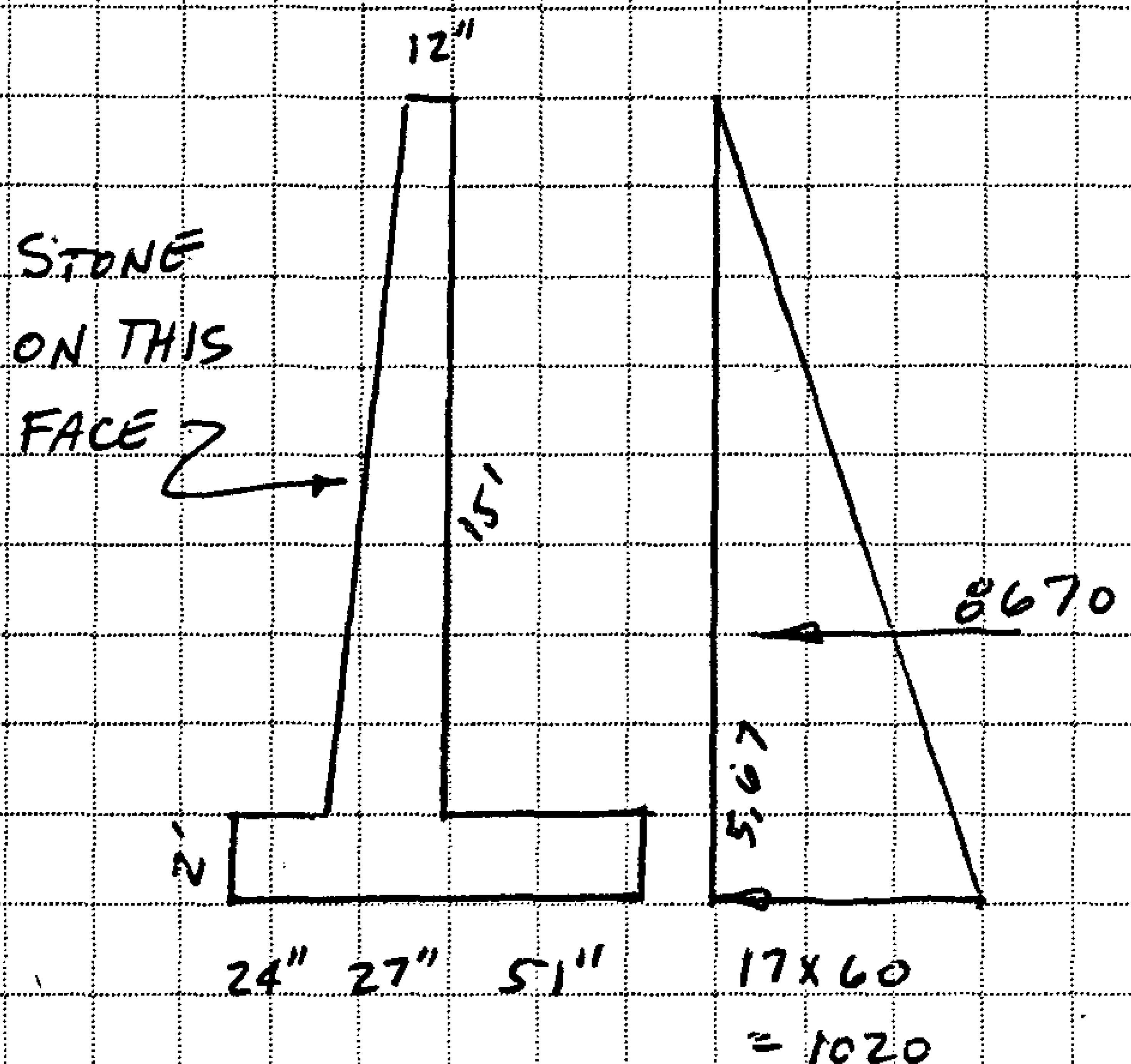
JOB 90783
SHEET NO. 41 OF
CALCULATED BY TAY DATE
CHECKED BY DATE
SCALE EAST FACADE WALL - CONCRETE



HIGH SIDE WALL

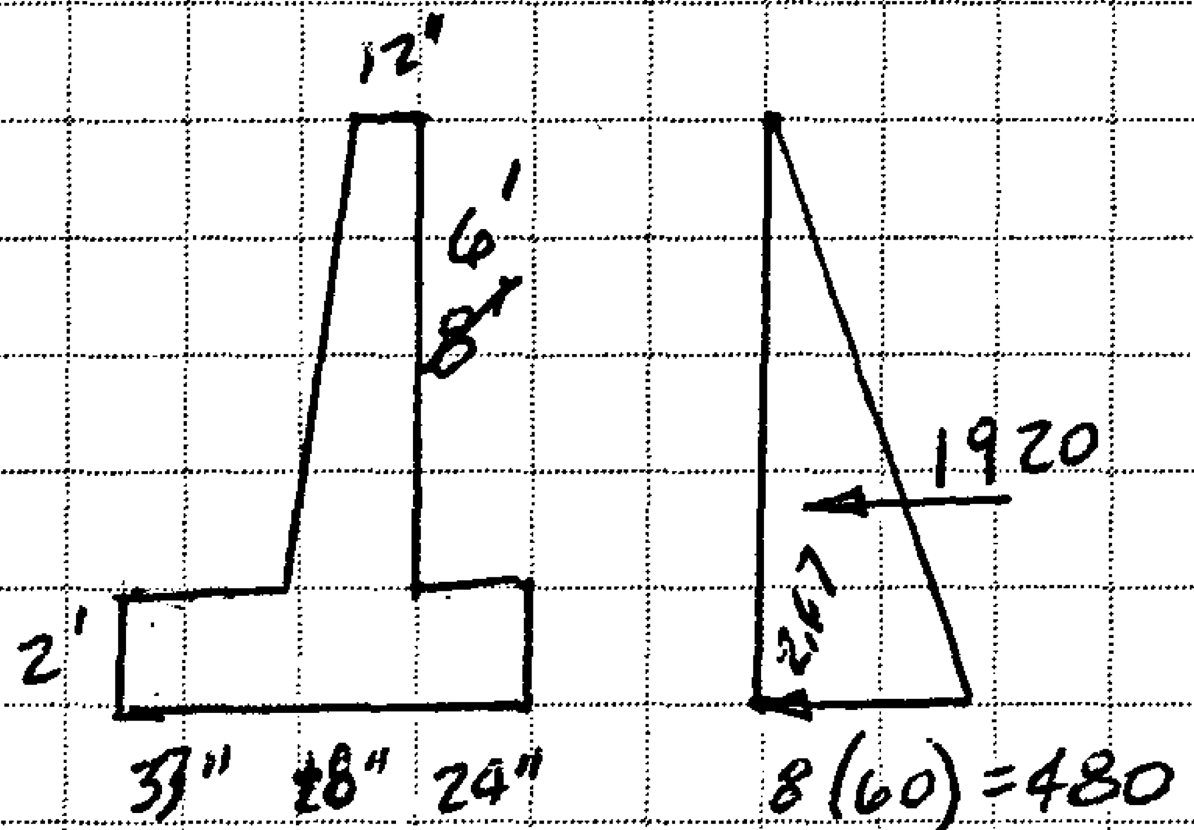
LOAD		MOMENT
2250	12" WALL $1 \times 15 \times 150 \times \frac{45}{12} =$	8440
235	Δ WALL $\frac{1}{2} \times \frac{15}{12} \times 15 \times 150 \times \frac{34}{12} =$	660
2550	FTG $8.5 \times 2 \times 150 \times 4.25 =$	10840
7650	SOIL $4.25 \times 15 \times 120 \times \frac{76.5}{12} =$	48770
12685		68710

$M_{SOIL} = 8670(5.67) = 49160$

F.S. = 1.40 SAY OK

SLIDING $\frac{12685 \times .4}{8670} = 0.585$

NEED KEY OR BOLTING OR MAKE CONTINUOUS AT CORNER



LOW SIDE WALL

LOAD		MOMENT
1125	AVG WALL $1.25(6) \times 150 \times \frac{41}{12} =$	3840
1900	FTG $6.33(2) \times 150 \times 3.17 =$	6020
1440	SOIL $2(6) \times 120 \times 5.25 =$	7560
4565		17420

$M_{SOIL} = 2.67(1920) = 5120$

F.S. = 3.40

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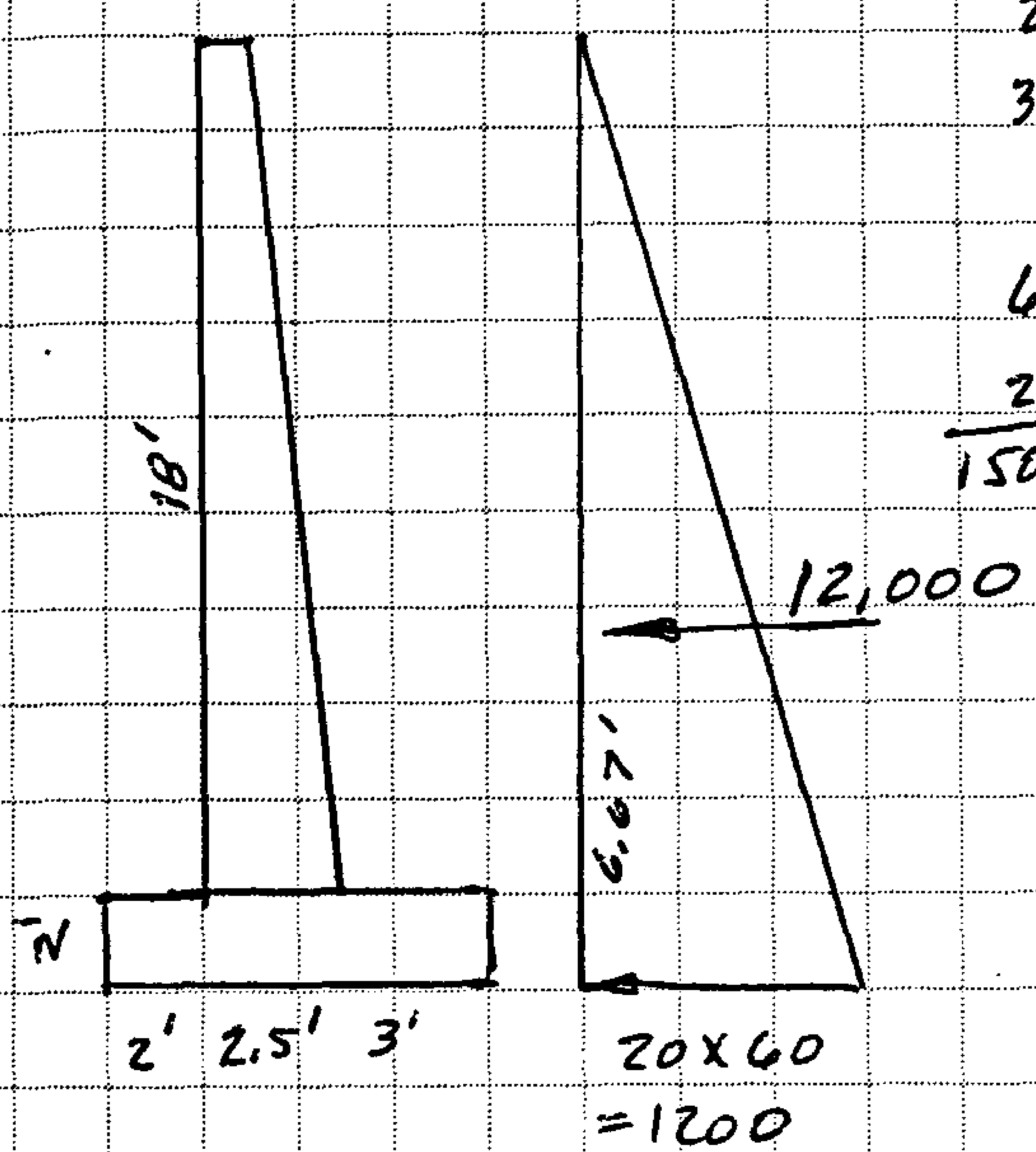
SCALE EAST FACADE - RETAINING WALL



LOADS			MOMENT
2700	12" WALL	1 X 18 X 150 X 2.5 =	6750
3240	18" WALL & SOIL	1.5 X 18 X 120 X 3.75 =	12150
405	CONC WEDGE	1.5 X 18 X ½ X 30 X 3.5 =	1420
6480	SOIL	3 X 18 X 120 X 6 =	38880
2250	FTG	7.5 X 2 X 150 X 3.75 =	8440
15075			67,440

$M_{SOIL} = 12000 (6.67) = 80,040$
$< 1.5 (67640)$
$= 101460$

2ND TRY 3' 2.5' 4'

HEADWALL

LOADS			
	12" WALL	2700 X 3.5 =	9450
	18" WALL & SOIL	3240 X 4.75 =	15390
	CONC. WEDGE	405 X 4.5 =	1820
8640	SOIL	4 X 18 X 120 X 7.5 =	64800
2850	FTG	9.5 X 2 X 150 X 4.75 =	13540
17,835			105000

$F.S. = \frac{105000}{80040} = 1.31$

ROCK 22.2
TOP OF HIGH WALL = 46.8
MIDDLE = 44.8
LOW = 42.2

SIDEWALL
TOP 39.4
LOW END 30.0
ROCK 22.2

EQ. FLUID PRESSURE
= 60 PCF

WALL IS 8.5' WIDE.
$1.5 (80040) - 105000 = 15060$
$15060 \times 8.5 = 128010$

TIE DOWN FORCE $= \frac{128010}{8.5} = 15,060$

ROCK BOLTS w/ F.S. = 4
$\frac{1}{3} \pi r^3 \, 120 = 15060 (4)$
$r^3 = 480$
$\Rightarrow r = 8' (\pm)$ (ONE BOLT OR TWO)
LENGTH OF BOLTS 8' (+)

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JOB 90783
SHEET NO. 43 OF
CALCULATED BY TAY DATE 10/90
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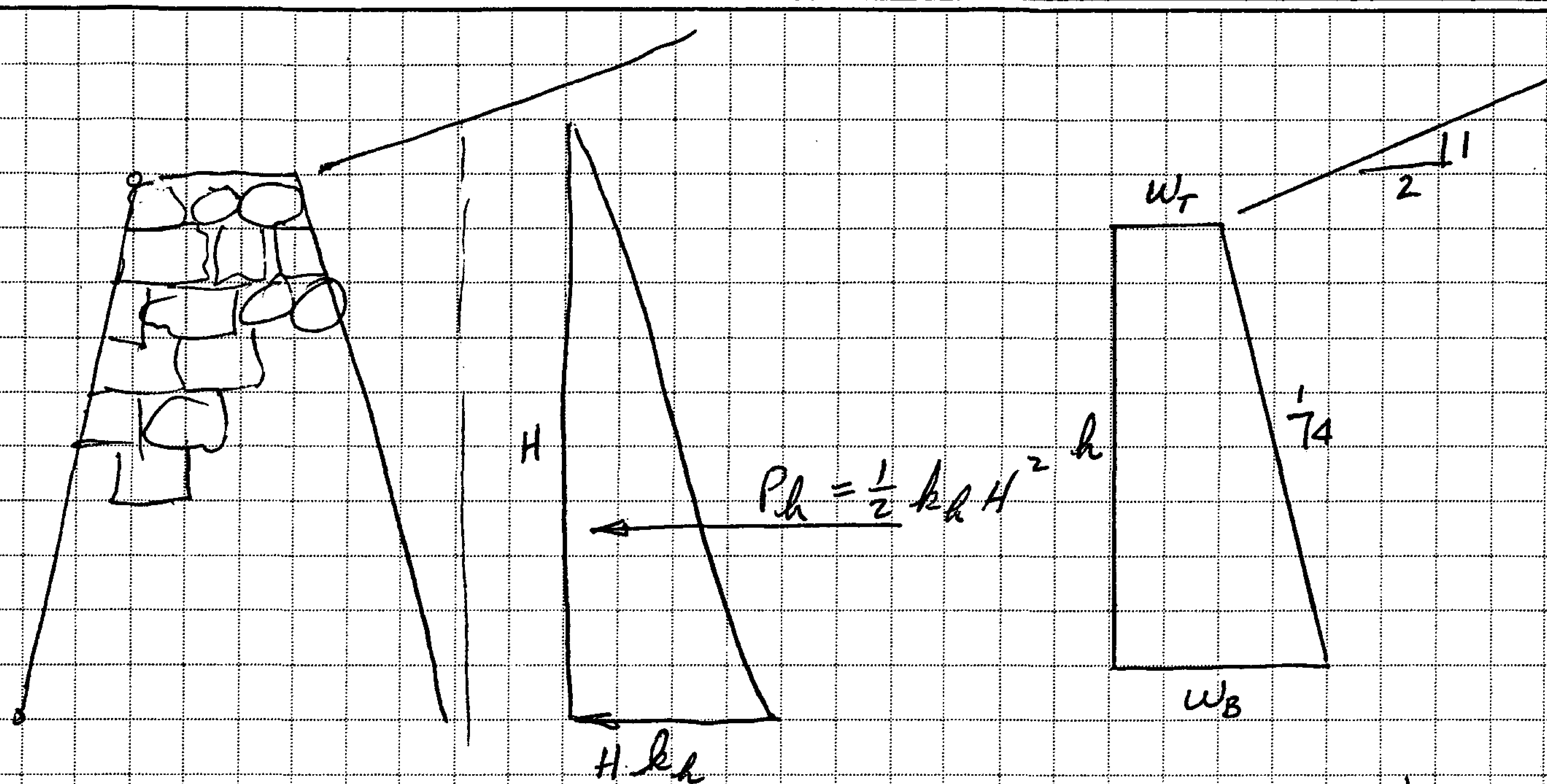
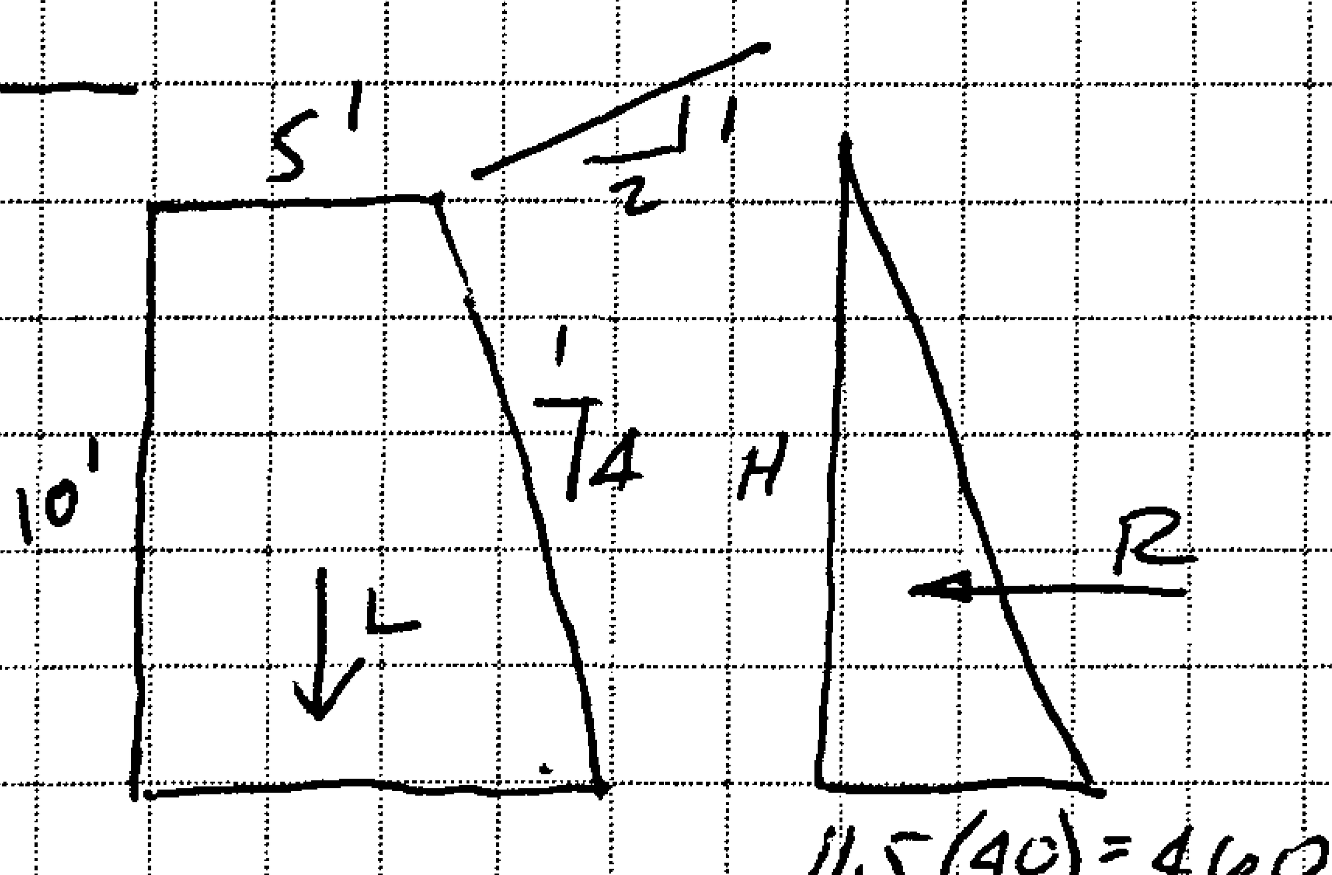
SCALE DRY LAID STONE WALLS



ASSUMED DESIGN SHAPE FOR WORST CASE, WITH FRONT BATTERED STABILITY IMPROVES

ASSUME WALL WT. = 120 pcf
ASSUME k_h = 40 pcf
DEVELOP F. OF S. = 1.5 FOR THIS LOAD



$H = 10 + \frac{1}{2}\left(\frac{10}{4}\right) \approx 11.5'$

$R = 460(11.5)(1/2) = 2645$ lbs

$M_R = 2645\,(11.5/3) = 10{,}140$

$L = (5 + 1.25)(10)(120) = 7{,}500$

FRIC. = 0.60 $F_L = 4500$ F.S. = 1.70

$M_L = 5(10)(120)(2.5) + 1.25(10)(120)(5 + 0.75)$

$M_L = 15{,}000 + 8625 = 23{,}625$

F.S. = 2.33

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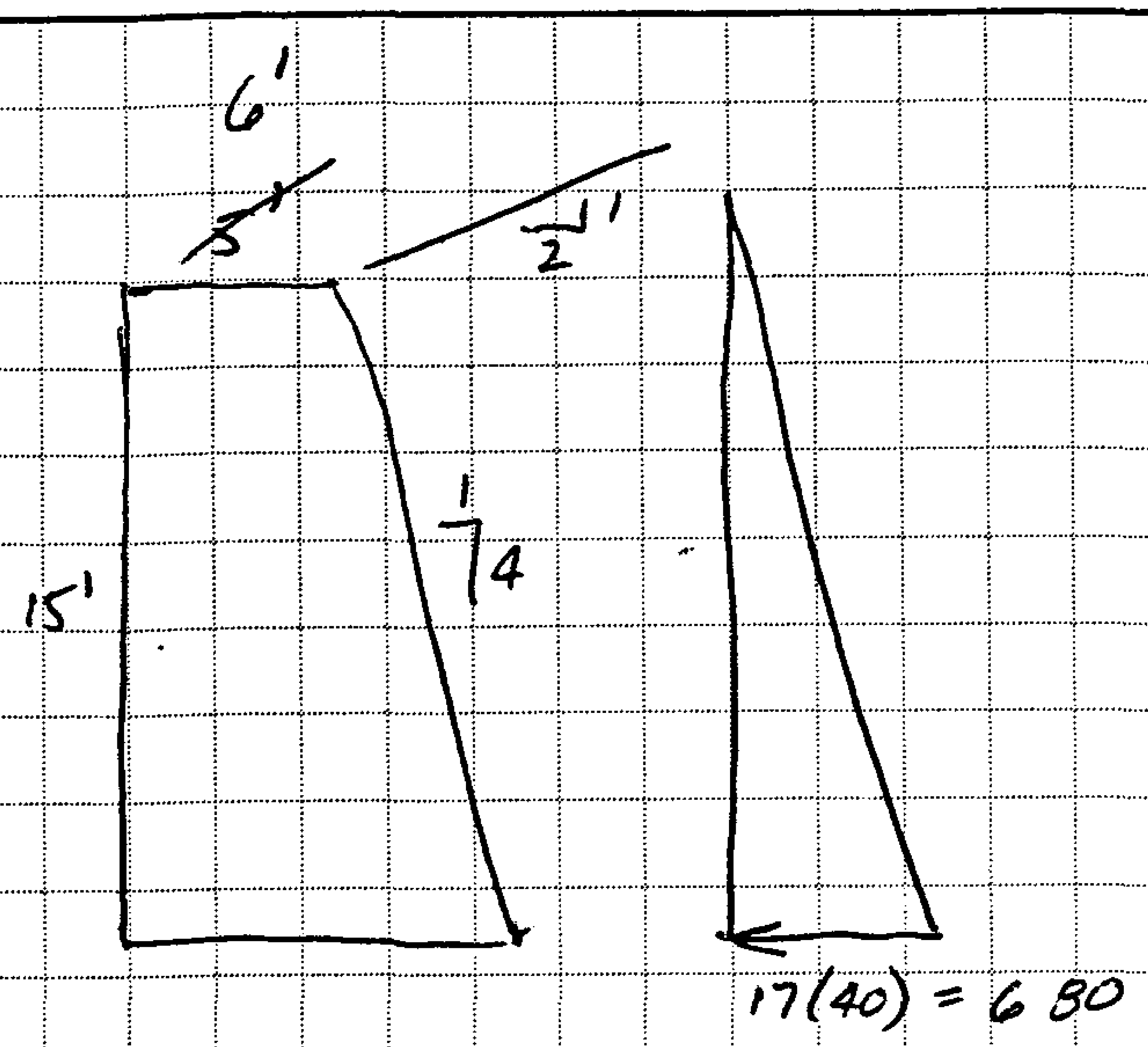
CHECKED BY DATE

SCALE DRY LAID STONE WALLS



$H = 15 + \frac{1}{2}\left(\frac{15}{4}\right) = 16.875'$ USE 17'

$R = 680(17)(\frac{1}{2}) = 5780$ #'s

$M_R = 5780(17/3) = 32,753$ '-#'s

$L = 15(5)(120) + \frac{3.75}{2}(15)(120)$

$L = 9000 + 3375 = 12,375$

FRIC = 0.60 $F_L = 7425$ F.S. = 1.28

$L = \frac{6}{5}(9000) + 3375 = 10800 + 3375$

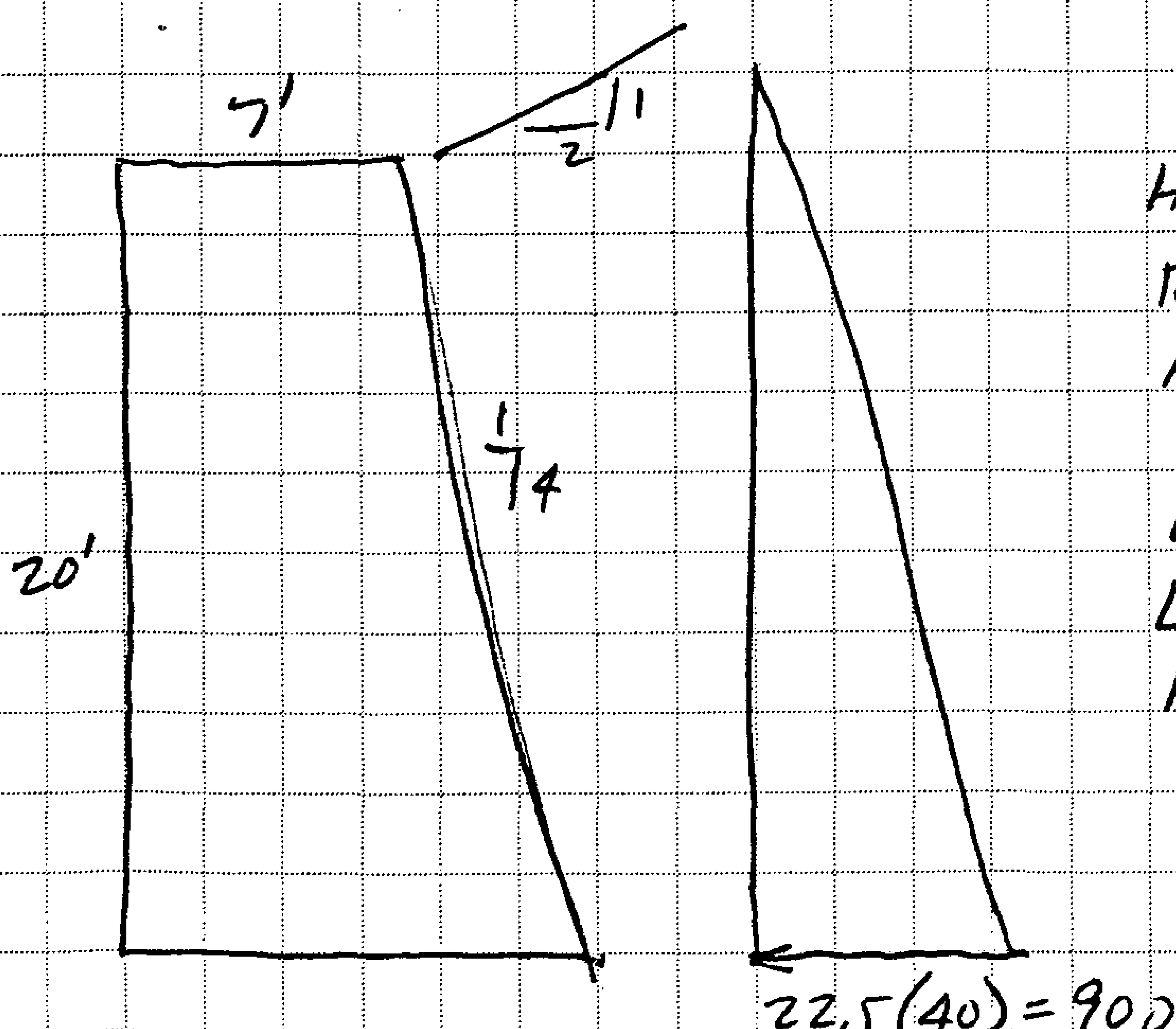
$L = 14175$

$F.S. = \frac{14175(.60)}{5780} = 1.47$ SAY OK

$M_L = 10800(3) + 3375(7.25)$

$= 32400 + 24470 = 56870$

$F.S. = \frac{56870}{32753} = 1.74$ SAY OK



$H = 20 + \frac{1}{2}\left(\frac{20}{4}\right) = 22.5$

$R = 900(22.5)(\frac{1}{2}) = 10,125$

$M_R = 10125(22.5/3) = 75,938$

$L = 20(7)(120) + \frac{5}{2}(20)(120)$

$L = 16800 + 6000 = 22,800$

FRIC $F.S. = \frac{0.60(22800)}{10125} = 1.35$ LOW

$M_L = 16800(3.5) + 6000(7 + \frac{5}{3})$

$M_L = 58800 + 52020 = 110,820$

$F.S. = \frac{110820}{75938} = 1.46$ OK

REVIEW NEED FOR 20' HIGH WALLS

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SHEET NO. 45 OF
CALCULATED BY TAY DATE
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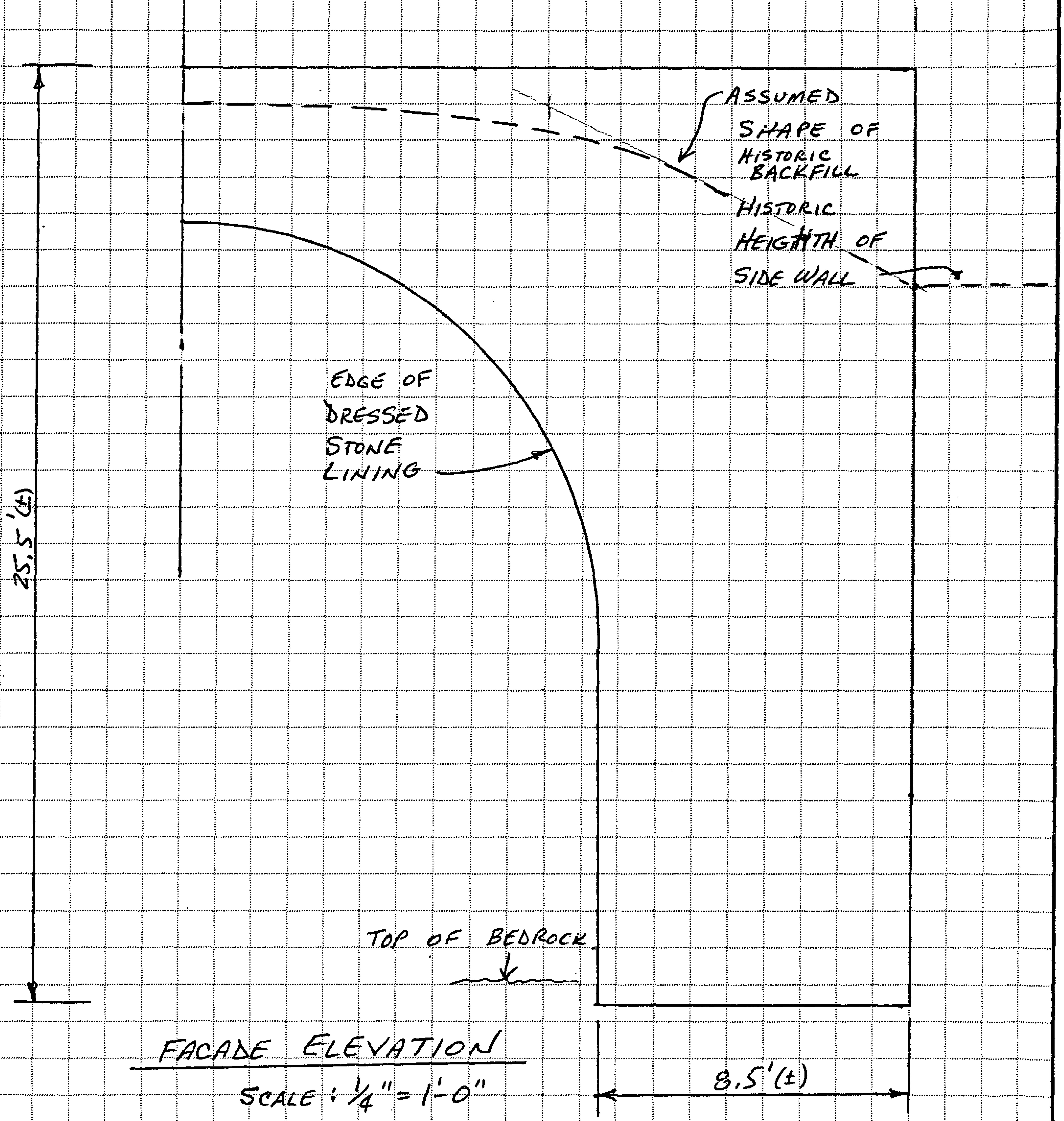
SCALE WEST FACADE



FACADE ELEVATION
SCALE: 1/4" = 1'-0"

PRODUCT 204-1 NEBS Inc., Groton, Mass. 01471.

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SHEET NO. 46 OF
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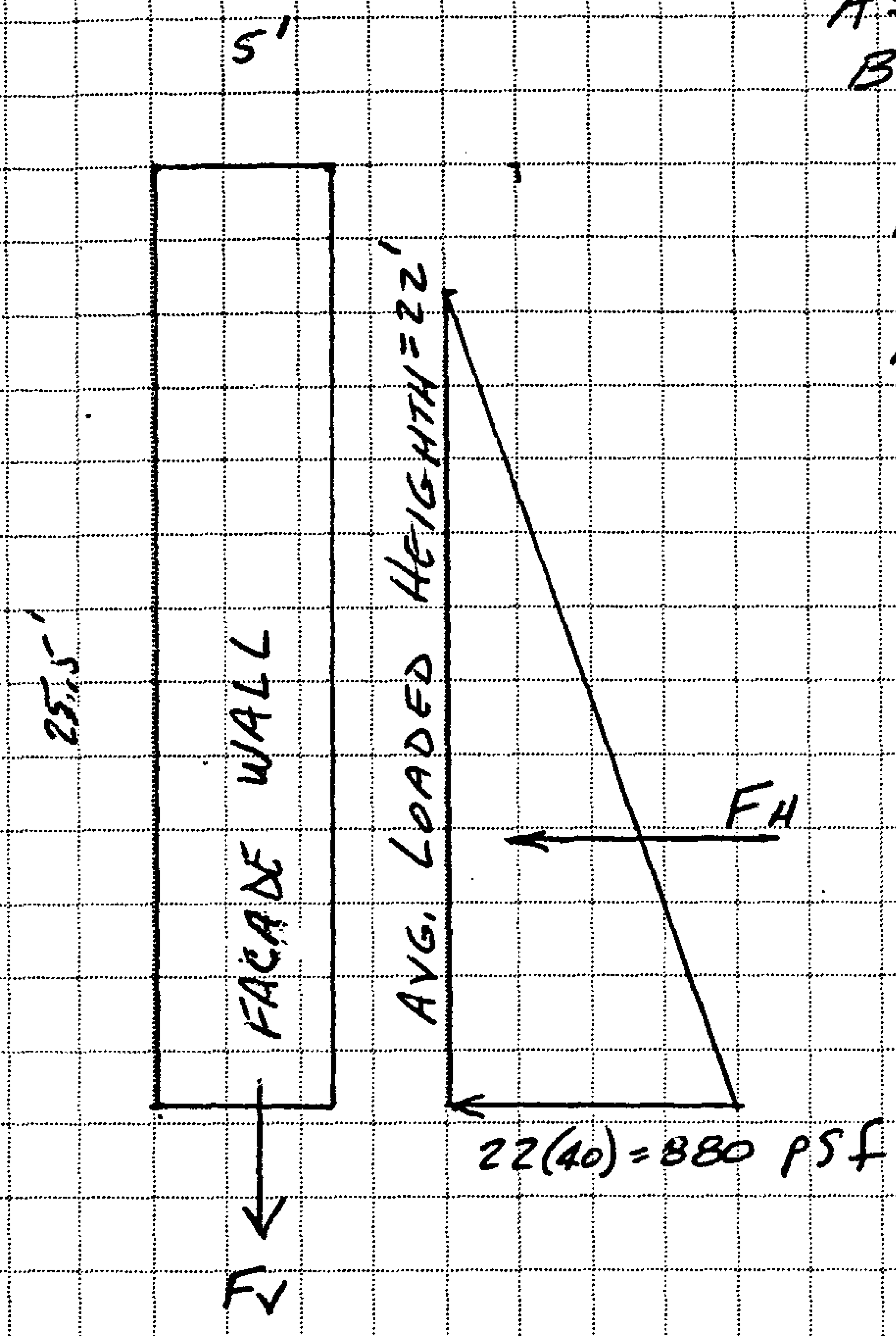
SCALE WEST FACADE



ASSUME EQUIV. FLUID PRESSURE = 40 PCF
BACKFILL SLOPE IS FAIRLY FLAT

$F_H = \frac{1}{2}(880)(22) = 9680$ #'s

$M_{FH} = 9680\left(\frac{22}{3}\right) = 70{,}990$ FT-LB

$F_V = 5(25.5)(160) = 20{,}400$ #'s
ASSUME WT. OF STONE

$M_{FV} = 20{,}400(2.5 - 0.2) = 46{,}920$ FT-lb
LEANING AVG.

70,990 > 46,920 FACADE IS NOT STABLE ON ITS OWN. IT MUST GET HELP FROM
1) FRICTION FROM LINING STONE INTERLOCK, AND
2) POSSIBLY ADDED WALL THICKNESS AT BASE ON BACKSIDE

@ OUTSIDE EDGE HEIGHTH LOADED IS 19.5'
$F_H = \frac{1}{2}(19.5)(40)(19.5) = 7605$ #'s
$M_{FH} = 7605\left(\frac{19.5}{3}\right) = 49430$ FT-LB
≈ 46920 FROM ABOVE
WITH FRICTION HELP, FACADE WALL IS VERY BORDERLINE. ORIGINALLY IT COULD HAVE BEEN STANDING WITH AN EXTREMELY LOW FACTOR OF SAFETY.

THE EAST FACADE PROBABLY COLLAPSED BECAUSE OF GREATER ACTIVE SOIL PRESSURE THAN ASSUMED ABOVE.

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SHEET NO. 47 OF
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SCALE WEST FACADE - SOIL LOAD

MOMENTS

WALL (~~10'~~ 8.5' WIDTH) SOIL

DIST. FROM TOP		M=2.5/load	AVG. HT.	LOAD PSF	LD	M
1	~~10~~ 8.5 (5)(160)(H)		0			
2						
3						
4						
5						
6	40,800	102,000	2.5	100	1060	885
7						
8	54,400	136,000	4.5	180	3440	5164
9						
10	68,000	170,000	6.5	260	7182	15,562
11						
12	81,600	204,000	8.5	340	12,280	34,800
13						
14	95,200	238,000	10.5	420	18743	65,600
15						
16	108,800	272,000	12.5	500	26560	110,680
18		306,000	14.5	580	33740	172,750
20		340,000	16.5	660	46280	254,553
22		374,000	18.5	740	58182	358790
24		408,000	20.5	820		

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CALCULATED BY T.A.Y. DATE 10/8/90
CHECKED BY DATE
SCALE (FROM SURVEY DATA)

WEST PORTAL PILASTER ANALYSIS

		NORTH COORD	EAST CORD.	ELEV.	ΔN	LENGTH	SLOPE FT/FT.
NORTH - LEFT							
TOP	7	141.17	132.81	40.54	0.20	7.40	.0270
MID-HT.	9	141.37	132.84	33.14	0.17	6.82	.0249
BOTTOM	11	141.50	132.83	26.32			
TOP	8	141.23	135.21	40.51	0.19	7.34	.0259
MID-HT	10	141.42	135.23	33.17	0.11	6.85	.0161
BOTTOM	12	141.53	135.23	26.32			
NORTH - RIGHT							
TOP	18	141.33	136.89	40.44	0.13	7.43	.0175
MID-HT.	16	141.46	136.90	33.01	0.09	6.69	.0135
BOTTOM	13	141.55	136.94	26.32			
TOP	17	141.32	139.28	40.55	0.13	7.54	.0172
MID-HT	15	141.45	139.29	33.01	0.11	6.69	.0164
BOTTOM	14	141.56	139.28	26.32			
SOUTH - LEFT							
TOP	19	141.46	163.60	40.51	0.10	5.49	.0182
MIDHT	26	141.56	163.66	35.02	0.15	8.70	.0172
BOTTOM	27	141.71	163.75	26.32			
TOP	20	141.45	166.04	40.47	0.08	5.45	.0147
MIDHT	25	141.53	166.02	35.02	0.15	8.69	.0173
BOTTOM	28	141.68	166.03	26.33			
SOUTH - RIGHT							
TOP	21	141.38	167.75	40.52	0.07	5.06	.0138
MID-HT	24	141.45	167.76	35.46	0.17	9.12	.0186
BOTTOM	29	141.62	167.77	26.34			
TOP	22	141.31	170.06	40.53	0.13	5.03	.0258
MID-HT	23	141.44	170.13	35.50	0.17	≈8.28	.0205
BOTTOM (GROUND 30)		141.61	170.14	27.22			

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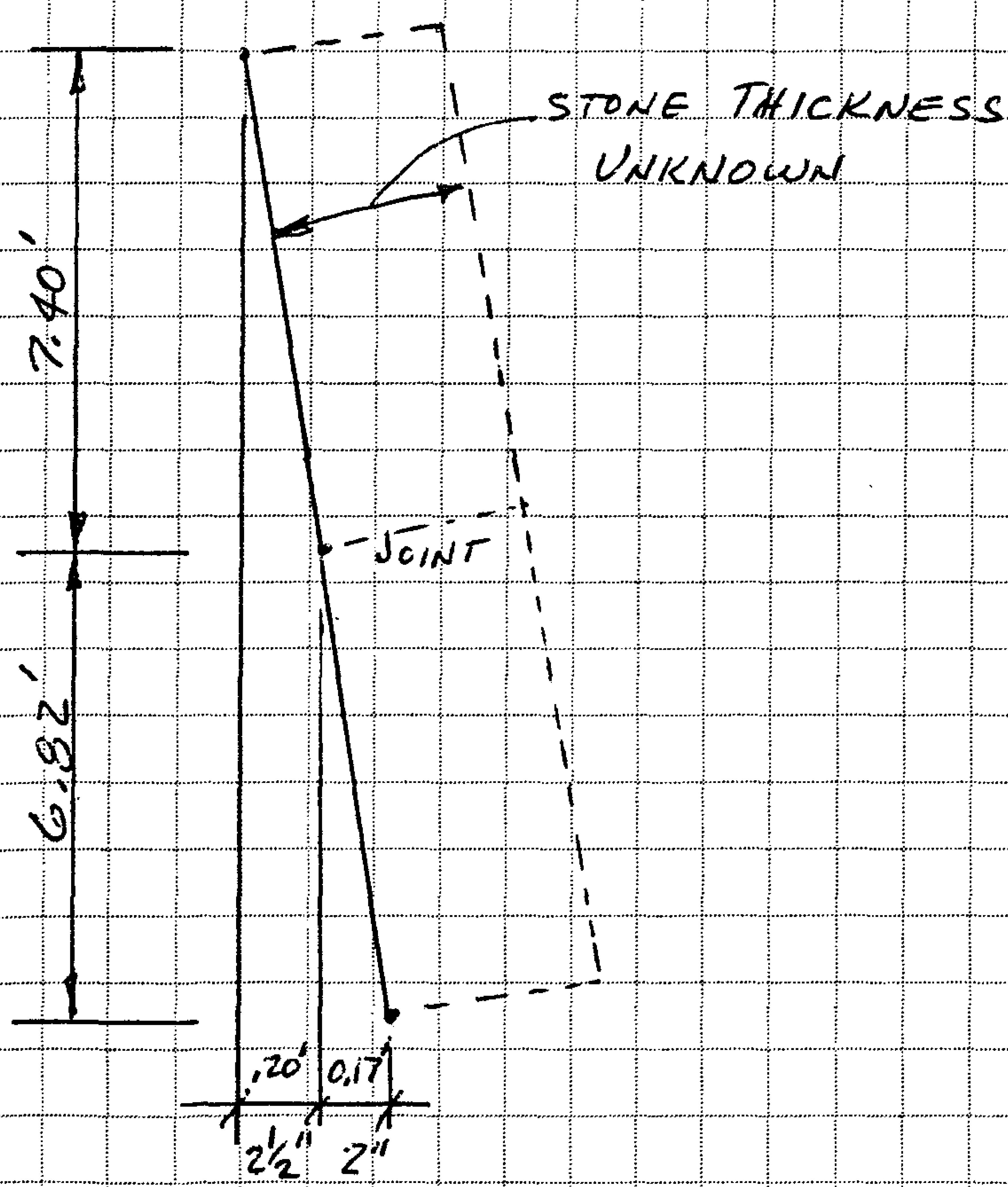
SCALE

WEST PORTAL PILASTER ANALYSIS - CONT.

AN E-W LINE IS THE BASIS OF MEASUREMENT ON THE WEST FACADE. THUS, DEVIATION IN EAST COORDINATES INDICATES OUT OF PLUMB FROM SIDE TO SIDE. DEVIATION IN NORTH COORDINATES INDICATES LEANING OUT OR IN. THE NUMBERS INCREASE TO THE NORTH. THEREFORE, THE SMALLER NUMBERS AT THE TOP INDICATE THE TOP IS OUT OVER THE BOTTOM.

THE OUTSIDE PILASTERS APPEAR TO BE 3½" TO 4½" OUT OF PLUMB, THE INSIDE PILASTERS 2½" TO 3".



NORTH PILASTER
NOT TO SCALE

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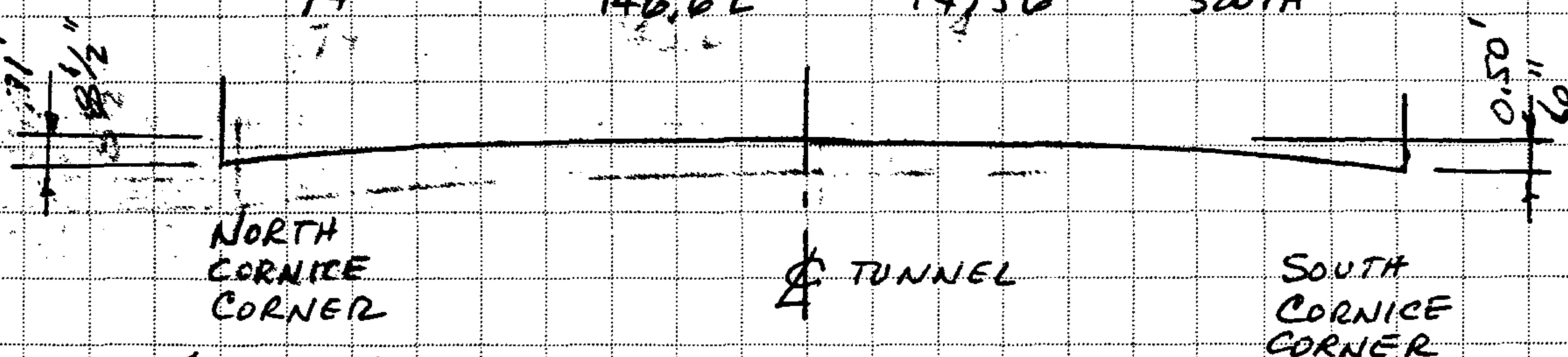
SCALE WEST FACADE

(FROM SURVEY DATA)

HORIZONTAL SHAPE OF FACADE

SURVEY PT.	N. COORD.	ELEV.	DESCRIPTION	
68	140.06	1446.06	NORTH	FRONT TOP OF CORNICE
69	140.77	45.96	CENTER	
70	140.27	46.01	SOUTH	
78	143.95	1446.03	NORTH	BACK EDGE OF CORNICE
75	144.72	45.97	CENTER	
72	144.19	46.13	SOUTH	
MISSING			NORTH	TOP OF 2ND ROW (BACK EDGE)
77	146.88	1444.38	CENTER	
74	146.62	44.56	SOUTH	



(MORE MOVEMENT FROM VARIOUS CAUSES AT THIS CORNER.)

PLAN AT CORNICE

FACE OF DRESSED STONE LINING AT FACADE

	SURVEY PT.	NORTH	ELEV.
N. SIDE	51	141.76	1426.01
	50	141.74	30.99
	48	141.72	35.74
	46	141.76	40.00
TOP	42	141.78	41.85
	39	141.79	39.42
	37	141.80	34.84
	36	141.77	31.07
S. SIDE	35	141.76	24.93

NOTE UNIFORMITY IN NORTH COORD. INDICATES NO SIGNIFICANT MOVEMENT. & THE STRUCTURE APPEARS TO BE VERY PLUMB.